Evidence for a Magnetic Seebeck Effect

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The irreversible thermodynamics of a continuous medium with magnetic dipoles predicts that a temperature gradient in the presence of magnetization waves induces a magnetic induction field, which is the magnetic analog of the Seebeck effect. This thermal gradient modulates the precession and relaxation. The Magnetic Seebeck effect implies that magnetisation waves propagating in the direction of the temperature gradient and the external magnetic induction field are less attenuated, while magnetisation waves propagating in the opposite direction are more attenuated.

Theory

- Irreversible thermodynamical relation

$$\mathbf{M}\nabla\mathbf{B} = \lambda n k_B \nabla T \quad \text{where } \lambda > 0$$

- Magnetic Seebeck effect (bulk)

$$\mathbf{B} = \varepsilon_M \times \nabla T \quad \text{where } \varepsilon_M = -\lambda n k_B (\nabla \times \mathbf{M})^{-1}$$

- Linearization:

$$\mathbf{B}_{\mathbf{ext}} = \mathbf{B}_0 + \mathbf{b} \text{ and } \mathbf{M} = \mathbf{M}_s + \mathbf{m} \quad \text{where } \mathbf{m} \ll \mathbf{M}_s$$

- Eigenmodes:

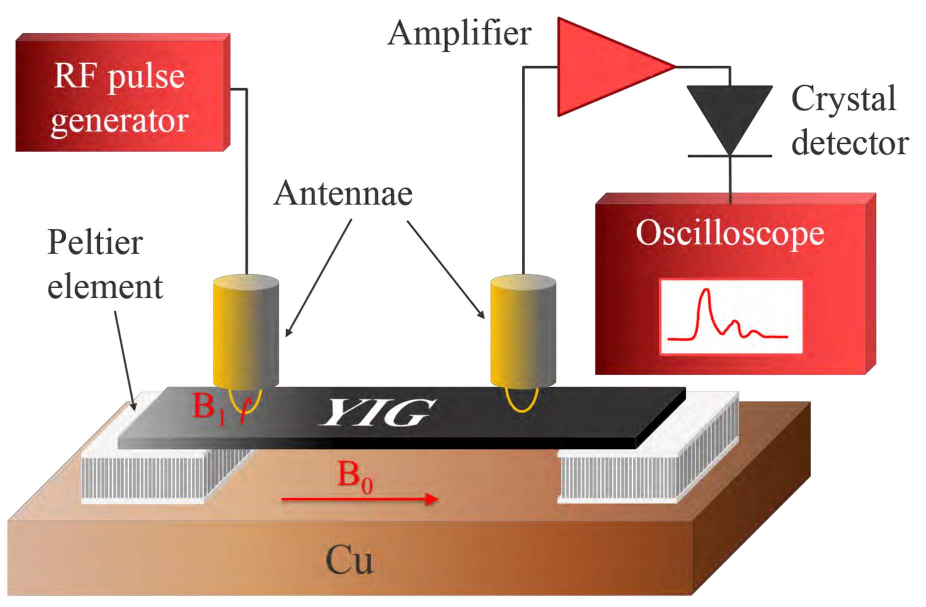
$$\mathbf{m}_{\mathbf{k}x,y} = \chi_{\mathbf{k}x,y}\mathbf{b}_{\mathbf{k}}$$

$$\chi_{\mathbf{k}x,y} = -\frac{1}{\Omega - \sqrt{\Omega_0(\Omega_0+1)} + i r_{x,y}(\alpha\Omega + \mathbf{k}_T \cdot \mathbf{k}^{-1})}$$

$$\mathbf{k}_T = \frac{\lambda n k_B}{\mu_0 M_S^2}\nabla T, \qquad \Omega = \frac{\omega}{\gamma \mu_0 M_S}, \qquad \Omega_0 = \frac{\gamma B_0}{\gamma \mu_0 M_S}, \qquad r_{x,y} > 0$$

Experimental Setup

Time-resolved transmission measurement of magnetization waves

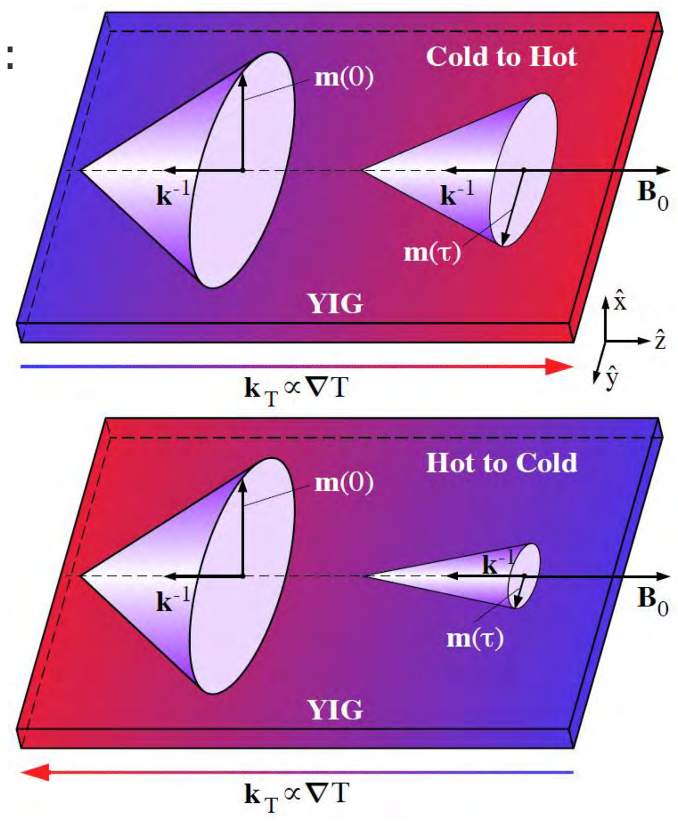


- Sample: YIG single crystal slab 10 mm x 2 mm x 25 µm
- Distance between antennae: 8 mm
- RF excitation: 4.36 GHz, 16 dBm , 15 ns pulse
- Temperature gradient ≈ 20K/cm

Theoretical Prediction

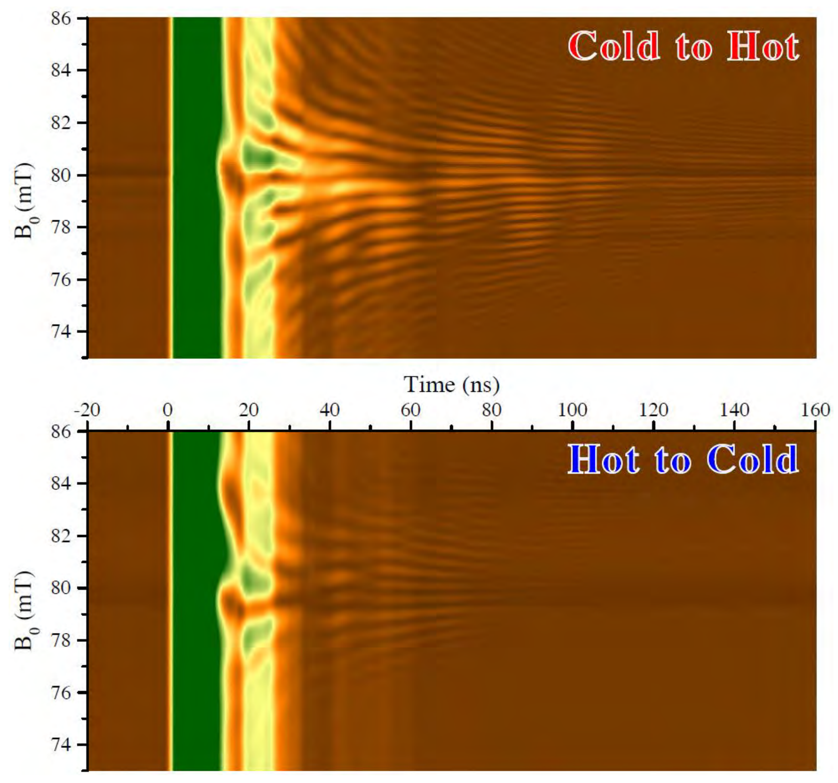
Magnetization waves propagation (YIG):

- Magnetostatic backward volume modes
- Cold to hot: negative thermal damping ($\mathbf{k}_T \cdot \mathbf{k}^{-1} < 0$)
- Hot to cold: positive thermal damping ($\mathbf{k}_T \cdot \mathbf{k}^{-1} > 0$)

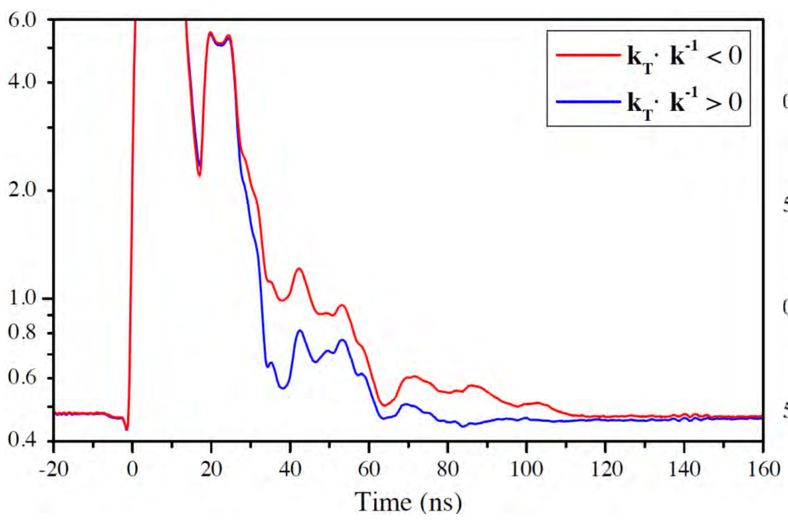


- The cones describe the precession of the magnetisation at excitation $\mathbf{m}(0)$ and at detection $\mathbf{m}(\tau)$.
- The amount of damping depends on the relative orientation $\mathbf{k}_T$ of the temperature gradient with respect to the magnetisation wave propagation direction $-\mathbf{k}^{-1}$

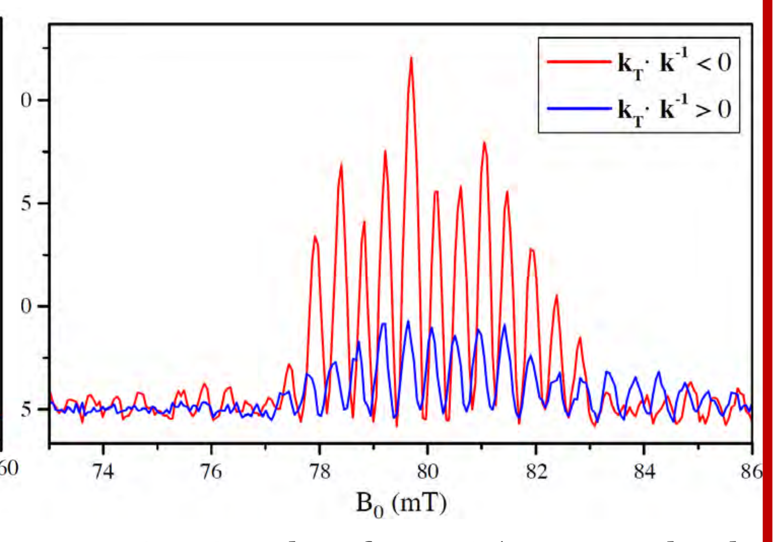
Experimental Results



- Transmitted signals from cold to hot side and from hot to cold side as a function of the magnetic field B_0 and of the detection time.
- **Waves propagating from the cold to the hot side decay less rapidly than the waves propagating from the hot to the cold side.**



Transmitted signal as a function of time averaged over the range of the magnetic field B_0



FMR signal of a 15 ns pulsed excitation detected after 70 ns, after baseline correction.

Conclusions

- Propagation of magnetization waves from cold to hot
  ⇒ less attenuation
- Propagation of magnetisation waves from hot to cold
  ⇒ more attenuation
- Effect on propagation of magnetization waves ∝ $\mathbf{k}^{-1}$

References

1. **S. D. Brechet, F. A. Vetro, E. Papa, S. E. Barnes and J.-P. Ansermet, "Evidence for a Magnetic Seebeck effect", Physical Review Letters 111, 087205 (August 22, 2013). Editor's suggestion.**
2. S. D. Brechet and J.-P. Ansermet, Eur. Phys. J. B 86, 318 (2013).
3. R. O. Cunha, E. Padrón-Hernández, A. Azevedo, and S. M. Rezende, Phys. Rev. B 87, 184401 (2013).

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