Experimental report

07/09/2022

Proposal:	**4-01-1671**	**Council:**	4/2020
Title:	Investiging the Magnon Contribution to the Spin Seebeck Effect in Rare Earth Iron Garnets by Polarised Inelastic Neutron Scattering		
Research area:	Physics		

This proposal is a resubmission of 4-01-1650

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Samples: Tb3Fe5O12 Dy3Fe5O12

Instrument	Requested days	Allocated days	From	To
IN20	7	5	15/03/2021	22/03/2021

Abstract:

We have been investigating the magnon contribution to the Spin Seebeck Effect measured in Tb3Fe5O12 at IN20 and IN12. The experiments are enabling us to construct temperature dependent Spin-W calculations of the magnons, which we want to map onto the thermal evolution of the SSE measurted in these systems. The aim of this proposal is to measure more of both low energy acoustic magnons and higher energy optical magnons to provide a better Spin-W model of the Temperature dependence of the magnons in this material. Currently the model lacks good agreement in both the high energy and low energy magnon regimes. We will also extenst these measurement to include Dy3Fe5O12 to provide a better overview of the SSE in the rare-earth iron garnets. We request 7 days in triple axis mode with polarisation analysis on IN20 for this experiment

Revealing the Magnon Contribution to the Spin Seebeck Effect in Tb3Fe5O12

Aim of Experiment

In experiment 4-01-1609 on IN20, we proposed to use Polarised Inelastic Neutron Scattering (PINS) to investigate the charality of the magnon contribution giving rise to the so-called Spin Seebeck Effect (SSE) [1-4]. The aim of the experiment on IN20 was to investigate chirality of the magnon modes in Tb3Fe5O12 (TbIG). The ReIG (Re=Gd,Tb,Y etc) are important to spintronics applications such as SEE, due to their long magnon lifetimes. The work is motivated by theoretical analysis fist applied to Gd3Fe5O12 [5], in which the thermal response of the SSE is proposed to be due to the interplay of low energy magnon modes of opposite chirality. This can be shown in figure 1(a), where the first optical mode (lowest blue parabolic curve), is shifted up in energy as temperature is lowered and eventually shifts above the thermal energy (horizontal flat line) around 40K (bottom panel). At low temperatures the magnons are dominated by acoustic Goldstone modes of opposite Chirality. This should then be responsible for an observed change in sign in the SSE voltage generated [5] at low temperatures.

In our experiments on IN20, we find clear evidence for the optical blue magnon mode as shown in ingure 1b. In a PINS experiment the chirality of a magnon band is evident by an asymmetry in the spin-flip intensities +- & -+. From the data in fig 1b we can conclude that the first optical mode has 100% chirality because the intensity is 100% in one of the -+ spin-flip channel. This later experiment focussed on obtaining more data on the higher energy modes towards a future publication.

However in the experiments on IN20 and later on IN12 (fig 1c) with higher energy resolution cold neutrons, we failed to observe any evidence of low energy dispersive Goldstone acoustic modes in TbIG. After a careful analysis of the data, we failed to find any clear evidence of a low energy acoustic mode as proposed in the theory for GdIG [5].

These results have puzzled us for a while and motivated new theory in collaboration with the ILL theory group and the university of Kent. In our theory, we use a simplified model to investigate the effects of the strong crystal-field levels of Tb^{3+} to the chirality dependent magnon modes involved in driving the SSE in TbIG [6]. Our simplified model is general for ReIG, and we obtain a measure of the energy as a function of the canting angles ($\theta_R, \theta_{\mathrm{Fe}}$) of the Re and of the Fe magnetic moments

$$\begin{aligned}\epsilon(\theta_R,\theta_{\mathrm{Fe}}) = &- K_e S^2 \cos^2(\alpha_o - \theta_R) + J_{cd} S s_d \cos(\theta_R - \theta_{\mathrm{Fe}}) \\ &+ J_{dd} s_d^2 (2\cos^2\theta_{\mathrm{Fe}} - \sin^2\theta_{\mathrm{Fe}})/2 \\ &- 2J_{ad}\ s_d s_a \cos^2\theta_{\mathrm{Fe}}\ .\end{aligned}$$

α_0 is a constant, K_e is the anisotropy constant for the easy-axis of the Re magnetic moment S. The constants J_{cd}, J_{dd}, J_{ad} account for the exchange couplings between the magnetic moments of the rare-earth (S, c-sites) and of the iron ions(s_d, d-sites; s_a, a-sites). This study has proven that the acoustic mode can become hybridised with the crystal field levels and is shifted to higher energies with mixed chirality [6]. These effects are expected to be negligible for GdIG, since Gd^{3+}-ions have a spin-only ground multiplet and should exhibit a negligible single-ion anisotropy. We are currently working towards a more detailed theory with the aim to fully reproduce our PNIS on TbIG, and to know more of ReIG as a class of materials.

New PINS experiments on a low absorption isotope of GdIG are required to test our new theory and provide a richer understanding of the ReIG SSE class of materials.

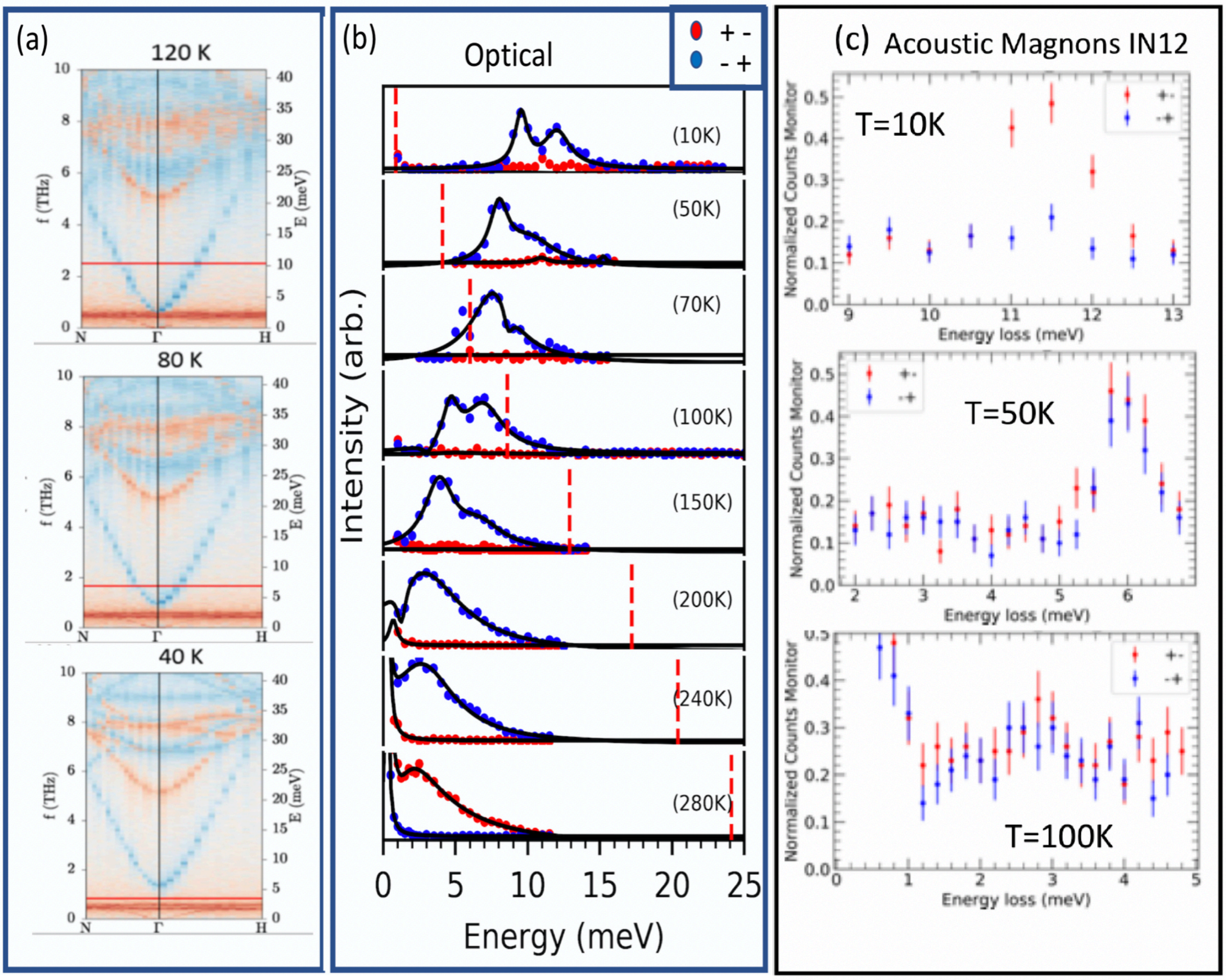

Figure 2 (a) left. Theoretical model of SSE [5]. The first parabolic (blue) mode is the optical mode of opposite chirality to the lower energy acoustic (flat-red) magnons. At high temperature >120K SSE response is dominated by the optical magnons. Below T<120K the optical modes become frozen out (horizontal line is thermal energy) as the band gap opens and the SSE response is dominated by acoustic magnons of opposite chirality (red). The model proposes that this effect causes an change in V(SSE) shown in fig 1b for T<100K. (b) middle. The measured optical magnons in SF channels +- (red) and -+ (blue) at Γ-point (444) on IN20, in qualitative agreement with theory (fig 2a). (c) right. The measured PINS in the spin-flip channels on IN12 at low energy loss. These magnon modes a not clear are not consistent with the model proposed for GdIG [5]: They are not purely chiral with both +- and -+ SF scattering and do not switch chirality above Tcomp.

References:

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