Experimental report

13/02/2019

Proposal: **4-01-1559**

Council: 4/2017

Title: Full polarization analysis neutronscattering investigation of the spin wave excitations in yttrium irongarnet

Research area: Physics

This proposal is a new proposal

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Samples: $Y3Fe5O12$

Instrument	Requested days	Allocated days	From	To
IN20	8	8	13/06/2018	21/06/2018

Abstract:

The recent observation of spin Seebeck effect in magnetic insulator yttrium iron garnet (YIG) attracts much attention because of the possible application in the spintronics. We thus have been performing unpolarized and polarized neutron inelastic scattering on large single crystal sample of YIG to investigate the spin excitations at elevated temperatures close to Tc. Especially the polarization dependent inelastic scattering experiment clearly showed the opposite sign in the polarization of the acoustic and optical magnetic excitation mode in an applied magnetic field in this ferrimagnetic material. Since the temperature dependence of the spin Seebeck effect in YIG might be closely related to the thermal activation of the gapped optical mode at elevated temperatures in addition to the activation of the acoustic mode at low temperature thereby changing the spin transport properties, a detailed full-polarization analysis investigation on the magnetic excitation modes in ferrimagnetic YIG is urgently needed for the microscopic understanding of the spin Seebeck effect. We thus propose an full polarization analysis inelastic scattering experiment on YIG using IN20.

Full polarization analysis neutron scattering investigation of the spin wave excitations in yttrium iron garnet

by K. Kakurai, Y. Nambu, M. Enderle, T. Weber, M. Boehm

The observation of the spin Seebeck effect (SSE) by Uchida et al. [1] is attracting much attention because this effect can be directly applied to the construction of thermal spin generators for driving spintronics devices, thereby opening the door to thermo-spintronics. The recent discovery of the SSE in magnetic insulators [2] adds an essential piece of information for understanding the physics of the SSE.

Most recently Uchida et al. [3] performed measurements on quantitative temperature dependence of longitudinal SSE at high temperatures in Pt/$Y_3Fe_5O_{12}$(YIG) systems. It is found that the magnitude of the SSE voltage rapidly decreases with increasing the temperature and disappears above the Curie temperature, confirming the necessity of the ferromagnetism in SSE. But the critical exponent of the SSE voltage in Pt/YIG was estimated to be much greater than that of the magnetization curve of YIG. This discrepancy indicates that the mechanism of the SSE cannot be explained in terms of simple static magnetic properties and rather calls for a dynamical magnetic interpretation of the effect.
We thus performed an inelastic neutron scattering investigation of YIG with polarization analysis on IN20.

We have focused on the acoustic and optical spin excitation mode at around Q=(4,4,-4) of this ferrimagnetic substance.

The picture shows the large, high-quality single crystal YIG sample for the experiment oriented with [hhl] zone in the scattering plane.

The sample was mounted in the horizontal field cryomagnet and a magnetic field of 0.3T parallel to the scattering vector was applied to magnetize the sample.
IN20 was used in the full polarization analysis mode with both curved Heusler (111) monochromator and analyzer. Fixed k_f=2.662 and 4.1 $Å^{-1}$ were chosen to cover energy transfer range up to 35 meV.

Fig. 1 displays the non-spin-flip scattering intensities I(+,+) and I(-,-), and the spin-flip scattering intensities I(+,-) and I(-,+) scattering in a constant energy scan at the energy transfer of ΔE = 27 meV around Q=(4,4,-4) in the [hh-h] direction at T=300K.
The spin flip scattering I(+,-) (blue open points) shows two spin excitation peaks at around QH=3.63 and 4.37, corresponding to the gapless ferromagnetic acoustic mode around Q=(4,4,-4).
The spin flip scattering I(-,+) (red open points) shows spin excitation peak at QH=4 and

this corresponds to the gapped optical mode with the gap energy of ~ 25 meV, as shown in the constant- Q energy scan at Q=(4,4,-4) in Fig.2.
In Fig.1, weak excitation peaks in the non-spin-flip scattering I(+,+) and I(-,-) (black and green open points, respectively) channels can be observed at QH=3.15 and 4.85, corresponding to the acoustic phonon mode. The weak, but finite intensities in the non-spin-flip scattering channels at the Q- and E-positions of magnetic excitations can be attributed to the finite polarization of the instrument, resulting to a small leakage of the (strong) magnetic spin-flip scattering intensity into the non-spin-flip channels.

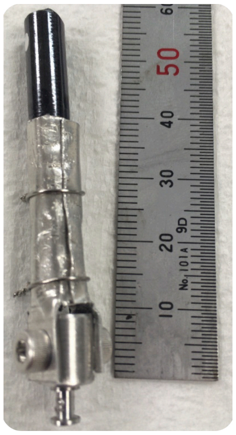
The intensity difference (I (+,-) - I (-,+)), corresponding to the chiral cross section, obtained from different constant-E and -Q scans around Q= (4,4,-4) are summarized in a colored contour map in Fig.3. One can clearly recognize the opposite polarization of the gapless ferromagnetic acoustic mode and the gapped optical mode.

We have also investigated the temperature dependence of the optical mode, which shows a substantial softening from 4 to 300K.

These experimental results are in good agreement with the recent theoretical prediction on the thermal spin dynamics of YIG invoking the method of atomistic spin dynamics [4] suggesting a strong suppression of spin transport in the ferrimagnet by large thermal populations of spin excitations with opposite polarization and hence to the suppression of the SSE.

These inelastic neutron polarization analysis results hence microscopically evidence the crucial role of the spin excitations in the SSE.

References:
[1] K. Uchida et al.: Nature 455, 778 (2008).
[2] K. Uchida et al.: Nature Materials 9, 894 (2010).
[3] K. Uchida et al.: arXiv 1408.2972.
[4] J. Barker and G.E.W. Bauer: Phys. Rev. Lett. 117, 217201 (2016)



Picture: YIG single crystal.

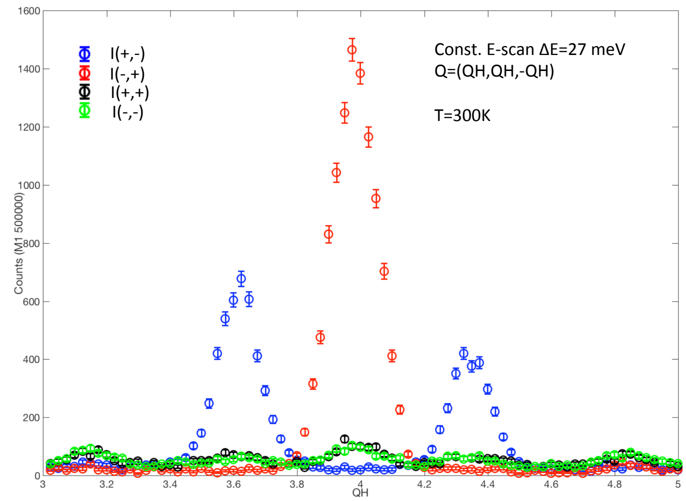


Fig.1: I(+,+), I(-,-), I(+,-) and I(-,+) scattering intensities at constant energy transfer of ΔE = 27 meV around Q=(4,4,-4) in the [hh-h] direction at T=300K.

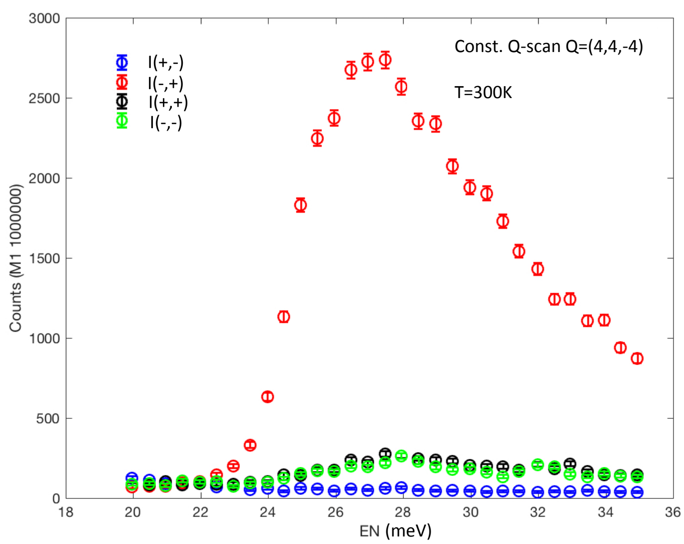


Fig.2: I(+,+), I(-,-), I(+,-) and I(-,+) scattering intensities in the constant- Q energy scan at Q=(4,4,-4).

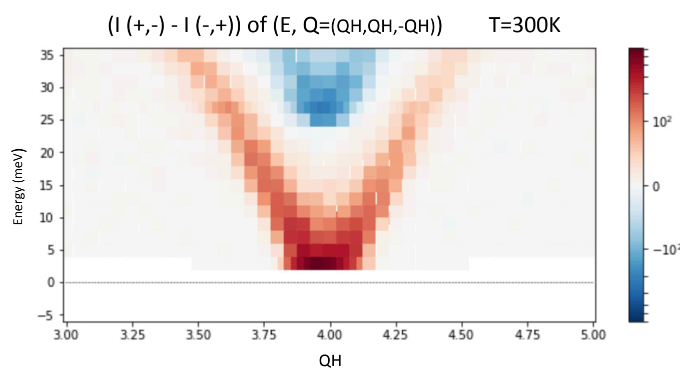


Fig.3: Summary of intensity difference I (+,-) - I (-,+) around Q= (4,4,-4).