Brillouin light scattering from surface and bulk spin waves in Co/Cu superlattices

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1. Introduction

Brillouin light scattering (BLS) is a widely used technique applied in GHz studies of magnons (spin waves) and acoustic phonons (acoustic waves). This is nondestructive method, easily applicable to small samples of arbitrary shape. Experimentally observed BLS spectrum possess characteristic strong line from elastic scattering, the Rayleigh line, and Brillouin peaks resulting from creation (Stokes lines) and annihilation (anti-Stokes lines) of phonons by photons.[1]

In the Co/Cu superlattices BLS is used to study influence of geometrical parameters, like structural period and number of layers, on spin wave dynamics as well as on elastic features.[2-8] In current experiment we worked with two kinds of samples grown in the [111] crystallographic direction. In the first sample the modulation period was equal to 100Å (60 Å Co + 40 Å Cu, sample 1), while the total number of bilayers was equal to 10. The second sample had a modulation period of 18Å (10 Å Co + 8 Å Cu, sample 2), with the total number of bilayers equal to 60. Thus the two samples had roughly the same total thickness. We have investigated the standing spin wave modes with exchange neglected, the dipolar coupled modes resulting from coupling of surface spin waves in each layer and the surface spin waves of the superlattice as a whole. The measurements were carried out as a function of magnetic field and for different angles of the incident light beam. Here, we present shortly results of the observed in-plane magnetic anisotropies, investigated through surface-type Damon-Esbach (D-E) modes and bulk-type modes. Results show 6-fold and 2-fold symmetries clearly visible for bulk-type spin waves and 2-fold symmetry for the D-E mode spectrum.

2. Experimental results. In-plane anisotropies

The experiment was carried out at room temperature with Sandercock-type 3+3 pass tandem Fabry-Perot interferometer. The samples were placed between the poles of water cooled electromagnet with about 6kG maximum value of magnetic field. As a light source a single-mode argon-ion laser (Coherent) was applied. All the measurements have been carried out for configuration where the polarization of incident light and scattered light was sensitive for spin waves - the polarization was perpendicular (p-s configuration).

Generally, there exist two types of modes in multilayered, metallic superlattices, composed of magnetic-nonmagnetic materials. The surface-type mode which frequency as a function of externally applied magnetic field H is equal to[7-8]

$$\omega_S = \gamma\left(H + 2\pi M\right), \qquad (1)$$

where γ is the gyromagnetic ratio, and M is the saturation magnetization. Next, the bulk-type modes which frequencies have following dependence on applied magnetic field[7-8]

$$\omega_B = \gamma\left[H\left(H + 4\pi M\right) + \left(2\pi M\right)^2 w\right]^{1/2}, \qquad (2)$$

where w is the band factor being a function of layer thickness and the magnon wave-vector components and falling in the (0–1) range. Both type of excitations are shown on Fig. 1. At this moment should be pointed out that only in artificially prepared superlattices special collective spin excitation are possible. The figure presents Brillouin spectrum obtained for one of the sample, for the 30° angle of light wave-vector incidence. The surface Damon-Eshbach mode is separated from bulk wave. This is possible when interlayer exchange contribution is negligible and the surface spin waves of each magnetic layer are coupled through dipolar interaction mechanism. The angle of incidence determines spin wave-vector length through the quasi-momentum conservation-principle. On the Fig. 2 spin waves frequency dependencies on the spin wave vector length are presented.

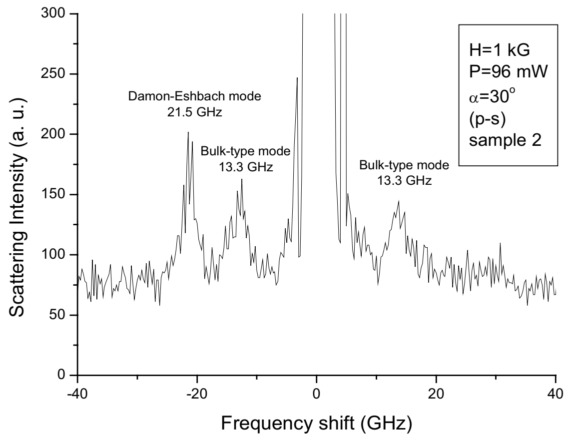

Fig. 1. Brillouin spectrum of the Co/Cu sample with 60 bilayers. The non-reciprocal signal was produced by the surface-type Damon-Eshbach mode.

For chosen angle of incidence, on the next figure (Fig. 3) measured dependencies expressed in the Eq. 1 and Eq. 2 are shown. The same standard results obtained for different in-plane directions but at constant spin wave wave-vector – the sample was rotated with 5 angular degree step - enabled us to study the in-plane magnetic anisotropies in a natural way correlated with crystallographic symmetry of the Co/Cu components (Fig. 4 - Fig. 5).

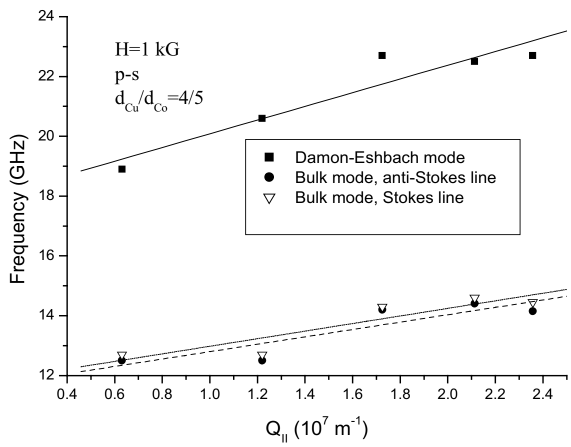

Fig. 2. Dependencies of spin waves frequencies on the wave-vector length determined by scattering geometry for crossed (p-s) polarization. The geometry is determined by angle of laser beam incidence on a sample. The sample plane was parallel to magnetic field and perpendicular to scattering plane – the plane determined by incident and scattered light wave-vectors.

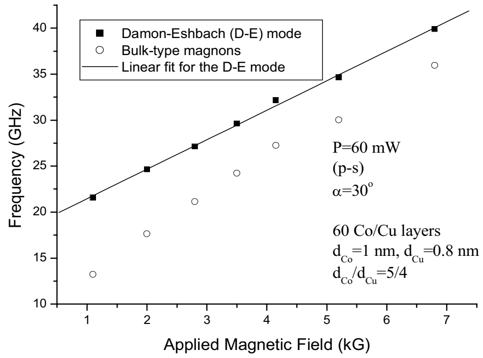

Fig. 3. Dependencies of surface Damon-Eshbach mode frequencies and bulk-type mode frequencies on magnetic field intensity applied. Theoretical dependencies can be found in Eq. 1 and Eq. 2.

This kind of measurements seems to be practical in research where information about in-plane anisotropies is needed. It is evident that surface-type mode results (Fig. 4) are less sensitive on bulk features, while bulk-type waves more clearly show 6-fold symmetry located in a bulk (Fig. 5).

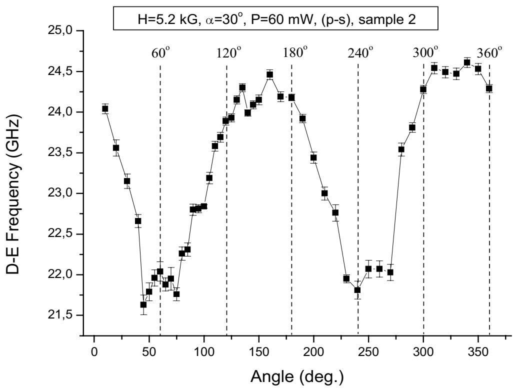

Fig. 4. Damon-Eshbach mode frequency as a function of sample orientation. The 2-fold symmetry is clearly visible.

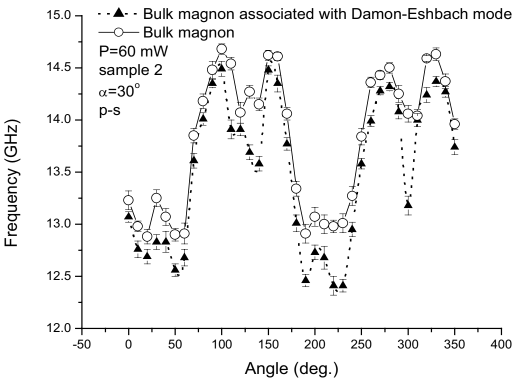

Fig. 5. Bulk-type mode frequency as a function of sample orientation. The 6-fold symmetry is superimposed on a 2-fold symmetry.

3. Conclusions

Spin waves frequencies have been measured for different experimental conditions, determined by magnetic field intensity and scattering geometry, showing two type of modes; Damon-Eshbach surface type and bulk-type. Presented results showed applicability of the method in investigations of in-plane magnetic anisotropies. It seems natural that surface-type mode results (D-E mode) are less sensitive on bulk features. However 2-fold symmetry is easy to recognize for the D-E mode as well. On the other hands bulk-type modes possessed information about both 2-fold and 6-fold symmetries. In that sense BLS seems to be very selective method to study different types of excitations located at different depth. It is interesting to point out that in a typical scattering experiment light penetrates about 300nm region in a nontransparent sample, when diffraction limit of collecting lens – the lens collecting scattered signals – is equal to about 30000nm. However, important physical information about BLS spectrum is assessable thanks to huge resolving power of the tandem Fabry-Perot interferometer.

It seems natural that such type of results should be update by the other experiments, like MOKE and RHEED techniques, to correlate measured magnetic anisotropies with crystallographic symmetries. Such types of measurements are very standard in metallic superlattices and have been carried out by authors.

References

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