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RESONANT SCATTERING OF MONOCHROMATIC PHONONS BY MAGNONS IN MnF$_2$ AND IN YIG

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Résumé.— En utilisant une spectroscopie de phonons par jonctions tunnel supraconductrices, nous avons observé la diffusion résonante phonon-magnon à 266 et 311 GHz dans MnF$_2$ orienté selon (001) et à 292 GHz dans YIG selon (110).

Abstract.— By using phonon spectroscopy with superconducting tunneling junctions resonant scattering of phonons by magnons has been observed at 266 GHz and at 311 GHz in MnF$_2$ along the c-axis and at 292 GHz in YIG along the (110) direction.

We have investigated the transmission of monochromatic phonons in a frequency range of 120 to 760 GHz in MnF$_2$ and in yttrium iron garnet (YIG). In these magnetic dielectric crystals the dispersion curves of phonons and magnons cross giving rise to a coupled mode in the crossover region /1/. These magnetoelastic waves have been extensively studied in the past by ultrasonic techniques in the GHz range /1/, and by thermal conductivity measurements at higher frequencies /2/. However, coupled magnon phonon modes could be observed as resonance dips in the thermal conductivity only in magnetic materials with a large magnetoelastic coupling constant, such as FeCl$_2$ /3/. In MnF$_2$ /4/ and in YIG /5/, where the magnon phonon coupling is weaker, resonant magnon phonon coupling could not be resolved in heat conduction. A more promising method for these materials seems to be phonon spectroscopy with superconducting tunneling junctions /6/.

For phonon spectroscopy at 1 K we used PbBi alloy junctions as generators and Al junctions as detectors. The monochromatic phonons were detected by an AC modulation technique, so a distinction between different phonon modes was not possible. Figure 1 shows the result of a transmission experiment for antiferromagnetic MnF$_2$ along the c-direction. Three lines are resolved at (184 ± 3) GHz, (266 ± 3) GHz and (311 ± 3) GHz. Using the magnon dispersion curve determined by inelastic neutron scattering /7/ and the elastic constants of R.L. Melcher /8/ we expect crossover points $\omega_m/2\pi = 321$ GHz with the transverse phonons and $\omega_m/2\pi = 268$ GHz with the longitudinal phonons in c-direction. (See also insert of Figure 1) We identify the upper two lines with these crossover points. The small deviation in the case of the transverse phonons may be attributed to the anisotropy of the phonons because of the finite resolution in solid angle of the detector.

This is supported by the observed width of the line being wider than the frequency resolution of the system. (The intrinsic linewidth of the resonance absorption which is of the order of the minimum separation $\Delta \omega$ of the dispersion curves in the crossover region is expected to be very small, as $\Delta \omega$ is estimated to be $2 \times 10^8$ s$^{-1}$/1,4/). Note that we see a line for the longitudinal phonons although...
these should not couple to the magnons along the anisotropy axis /1/. This seems to be also an effect of the finite resolution in solid angle of the detector. The pronounced line at 184 GHz lies well below the magnon energy gap. It may be due to \( \text{OH}^- \) impurities which are known to cause a resonance in the thermal conductivity of \( \text{MnF}_2 \) at 1 K /9/.

In the case of ferrimagnetic YIG the magnon and phonon dispersion curves are very isotropic and the magnon branch at zero magnetic field may be approximated by \( \omega(k) = D(ak)^2 - E(ak)^3 \) for this experiment where \( a \) is the lattice constant. \( D \) and \( E \) are linear combinations of the exchange parameters /10/ and have been determined by various experiments /11/. Using \( D = 30 \, \text{cm}^{-1} \) and \( E = 4.5 \, \text{cm}^{-1} \) and the elastic constants of S. Haussühl et al. /12/ we expect transverse magnon phonon resonance for \( \omega = 289 \, \text{GHz} \). (See also insert of Figure 2). The resonance with the longitudinal phonons lies above the frequency range of our experiment. Figure 2 shows the differential phonon signal as a function of frequency for YIG along (110). The absorption line observed at \((292 \pm 3) \, \text{GHz}\) agrees quite well with the expected crossover point for the transverse phonons. The experimental linewidth of 16 GHz is determined by the frequency resolution of the detecting system. (The intrinsic linewidth is expected to be smaller as the splitting \( \Delta \omega \) of the dispersion curves at the crossover point is approximately \( 5 \times 10^5 \, \text{s}^{-1} \) for YIG /1/). Compared with \( \text{MnF}_2 \) the absorption strength in YIG is larger because of the stronger magnetoelastic coupling. Additionally we have observed a broad absorption line at 435 GHz. This line did not vanish in a magnetic field sufficiently high to align the domains. It may be caused by impurities probably by Pb or \( \text{Fe}^{3+} \) which have a high concentration in the crystals used /12/.

We would like to thank R.L. Melcher for the \( \text{MnF}_2 \) crystal and W. Tolksdorf for the YIG crystal.

See also insert of Figure 2. The resonance with the longitudinal phonons lies above the frequency range of our experiment. Figure 2 shows the differential phonon signal as a function of frequency for YIG along (110). The absorption line observed at (292 \pm 3) GHz agrees quite well with the expected crossover point for the transverse phonons. The experimental linewidth of 16 GHz is determined by the frequency resolution of the detecting system. (The intrinsic linewidth is expected to be smaller as the splitting \( \Delta \omega \) of the dispersion curves at the crossover point is approximately \( 5 \times 10^5 \, \text{s}^{-1} \) for YIG /1/). Compared with \( \text{MnF}_2 \) the absorption strength in YIG is larger because of the stronger magnetoelastic coupling. Additionally we have observed a broad absorption line at 435 GHz. This line did not vanish in a magnetic field sufficiently high to align the domains. It may be caused by impurities probably by Pb or \( \text{Fe}^{3+} \) which have a high concentration in the crystals used /12/.

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