MUSHROOM Science Case Study 3

Future directions – Excitations in nanostructured functional materials

Nano-engineered materials are often deployed in an industrial context, from non-stick coatings to computer hard drives, and although the study of the structure of these materials is a mature field, the influence of nanostructure on the dynamical properties of these materials is much less studied. The small sample volume of these materials makes time-of-flight inelastic neutron scattering measurements impossible with current instrumentation. However, the high flux on MUSHROOM – at least 20 times that of LET - will permit measurements on samples of 20 times less volume. For example, measurement of a 10 μm film on MUSHROOM equates to measuring a 0.2 mm thick sample now, which is routine on LET.

Phononic and magnonic crystals are the structural and magnetic analogues of photonic crystals (composite nanostructured materials with periodic varying refractive index). In each of these, Bragg scattering of the phonon/magnon excitations due to the periodic nanostructure leads to band-gaps in the phonon/magnon dispersion. Figure 1 (a) [1] shows a theoretical example of a 3d phononic crystal, consisting of Si isotopes of varying periodicity (2 and 4 unit cells). The calculated phonon dispersion (b) reveals the presence of band gaps in the 4 unit-cell-crystal near the R-point of the Brillouin zone, with associated reduced phonon velocities (c). This leads to reduced thermal conductivity, and represents a possible route to high quality thermoelectric materials.

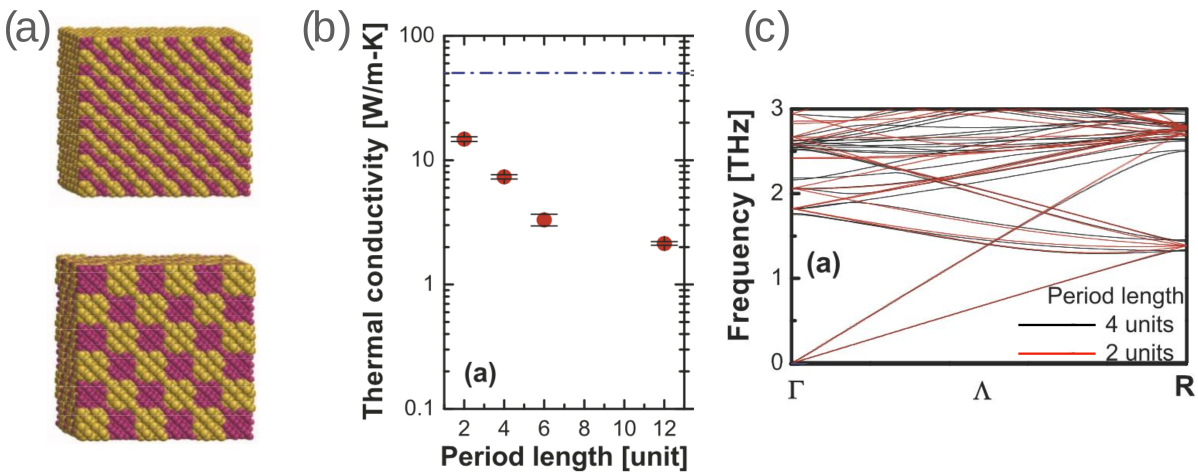

Fig. 1 – Si phononic crystal (a), with calculated thermal conductivity (b), and phonon dispersion (c) – reproduced from [1].

In a similar vein, nanostructured magnonic crystals, with periodic regions of different magnetisation or magnon velocities can be fabricated. These can be used in magnonic logic devices (e.g., magnonic transistors) and as magnon waveguides. Fig 2 (left) shows a realization of a one dimensional magnonic crystal (alternating permalloy and Co layers) with the associated spin-wave dispersion displaying large bandgaps (right) measured by Brillouin light scattering spectroscopy (BLS) reproduced from ref [2]. While the energy range, gap widths and momentum transfers in this example are clearly beyond what MUSHROOM could achieve, the direction of travel for these functional materials is towards thinner layers, shorter wavelengths and higher frequency devices - where MUSHROOM would come into its own [2].

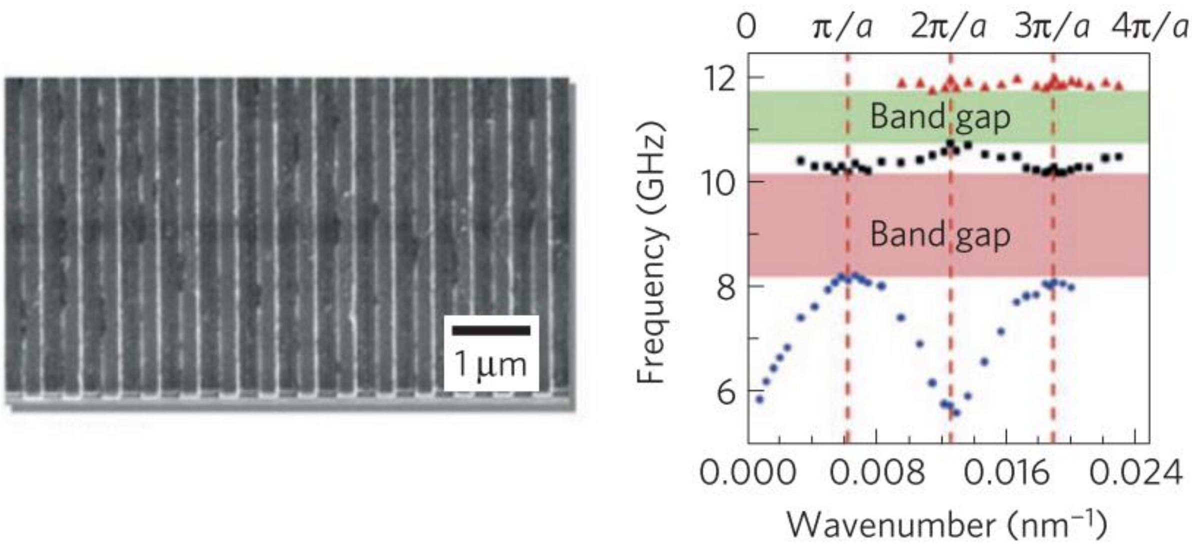

Fig. 2 – One-dimensional magnonic crystal of Py/Co layers (left) with spin-wave dispersion showing large bandgaps (right) - measured by BLS. Taken from ref. [2].

Even with the large flux increases expected with MUSHROOM, it is clear that INS experiments on these systems will provide a stern test of its capabilities. However, it is only now, with the flux increases that MUSHROOM will provide, that these experiments are even thinkable. MUSHROOM would be especially well adapted to study lower dimensional nanomaterials (1d or 2d) in which the dispersion would be measurable in a single shot (without the need for rotation of the sample).

References

[1] L Yang, *et al.,* Reduction of thermal conductivity by nanoscale 3D phononic crystal. *Scientific Reports*, ***3***, 1–5 (2013) https://doi.org/10.1038/srep01143

[2] A V Chumak, *et al.,* Magnon spintronics. *Nature Physics*, ***11***, 453–461 (2015) https://doi.org/10.1038/nphys3347