Influence of the demagnetizing field on the spin-wave softening in bicomponent magnonic crystals

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Abstract

In bi-component magnonic crystals (MCs) demagnetizing field occurs around interfaces between a matrix and inclusions. As it is already shown this field strongly influences the spin-wave spectrum including the position and the width of band gaps and their response to the change of the external magnetic field [1, 2]. Here, we show its effect on the reversal of the mode order in the spectrum. The reversal of modes means that the modes which are excited mostly in the material with higher saturation magnetization have lowest frequencies then modes excited in the material with low saturation magnetization. We address this effect to the mode-dependent softening of spin waves resulting from the growing influence of the demagnetizing field while the external magnetic field lowers. The effect gives a possibility of tuning the concentration of spin-waves in one of the constituent materials – the matrix or scattering centres – by the external magnetic field. As an example, we study planar bi-component MCs consisting of cobalt inclusions in permalloy matrix, as well as Py inclusions in Co matrix. We show that in both cases lowering external magnetic field drives down in the spectrum these modes which are excited mostly in Co. Moreover, the concentration of such modes in Co is enhanced.

The model

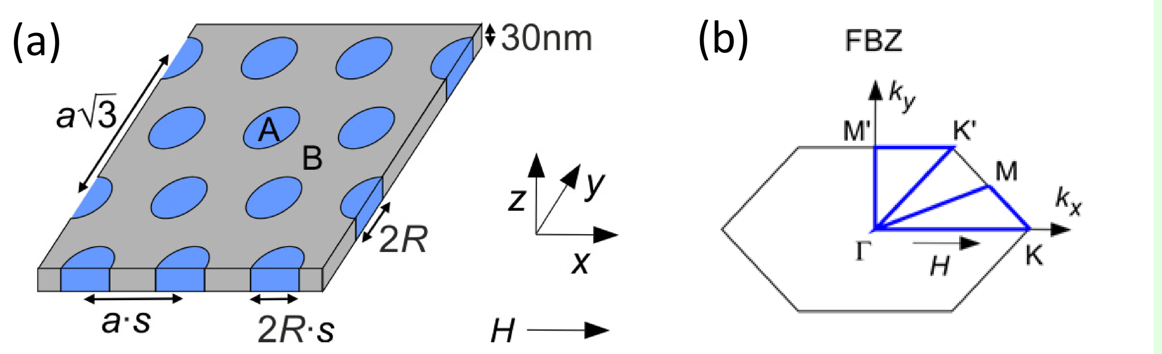

Fig. 1. (a) 2D MC based on the squeezed hexagonal lattice: a thin-film matrix made from material B with dots of material A embedded in. The structure is squeezed in the x direction (the direction of the external field H) by the structure ratio s. (b) First Brillouin Zone (FBZ) – for the squeezed structure is stretched. High symmetry path is marked with blue lines.

Concentration factor
- describes how much the spin waves prefer to be excited in one material.
For Co:

$$cf_{\mathrm{Co}} = \frac{\tilde{m}_{\mathrm{Co}}}{\tilde{m}_{\mathrm{Co}} + \tilde{m}_{\mathrm{Py}}}$$

$$\tilde{m}_X = \frac{1}{S_X}\int_{S_X} |\boldsymbol{m}|^2 dS$$

$$X = \mathrm{Co/Py}$$

Conclusions

- The in-Co concentration of spin waves can be enhanced by squeezing of the structure as well as by changing of the in-plane external magnetic field magnitude. In both cases, the crucial role is played by the demagnetizing field.
- This results in nonuniform softening of modes which may lead to the opening of complete band gaps sensitive to the external magnetic field at low fields.
- One can design this sensitivity by the squeezing of the magnonic crystal (tailoring of the demagnetizing field).
- This gives a possibility to tune the gaps in operando by the external magnetic field and squeezing.

References:

[1] S. Mamica, M. Krawczyk, D. Grundler, Phys. Rev. Appl. **11**, 054011 (2019), arXiv: 1810.04005

[2] S. Mamica, M. Krawczyk, Phys. Rev. B **100**, 214410 (2019), arXiv:1906.07469

Spin-wave softening in Co/Py MCs

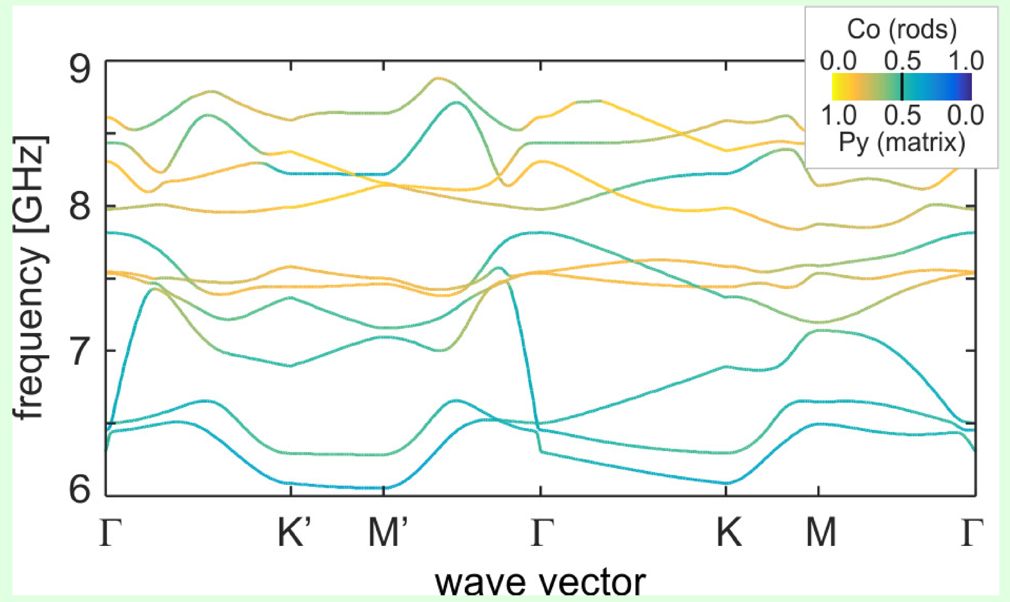

Fig. 2. Spin-wave spectra of Co/Py 2D MCs along the high-symmetry paths in the FBZ. Line colors depict the concentration factor according to the color scale shown in the inset. Three lowest modes are concentrated similarly in Co and Py.

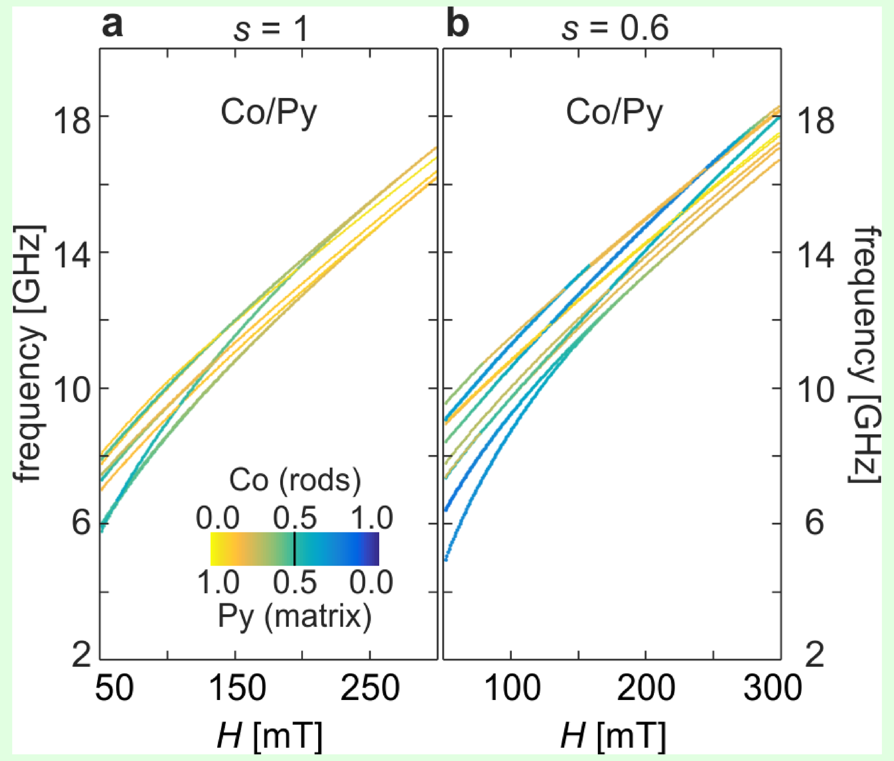

Fig. 3. Ten lowest frequencies of the spin waves vs. external field H calculated in the FBZ center (k = 0) for (a) s = 1 and (b) s = 0.6. Line colors – the same as in Fig. 2. Mode softening (right → left) = growing in-Co concentration.

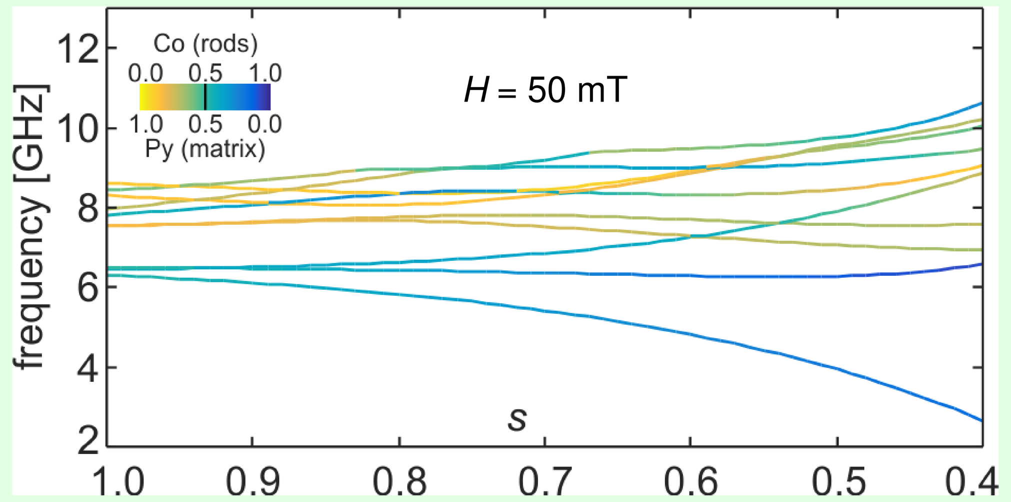

Fig. 4. Ten lowest frequencies of the spin waves vs. structure ratio s calculated in the FBZ center (k = 0) for H = 50 mT. Line colors – the same as in Fig. 2. Concentration in Co grows with squeezing.

Spin-wave softening in Py/Co MCs

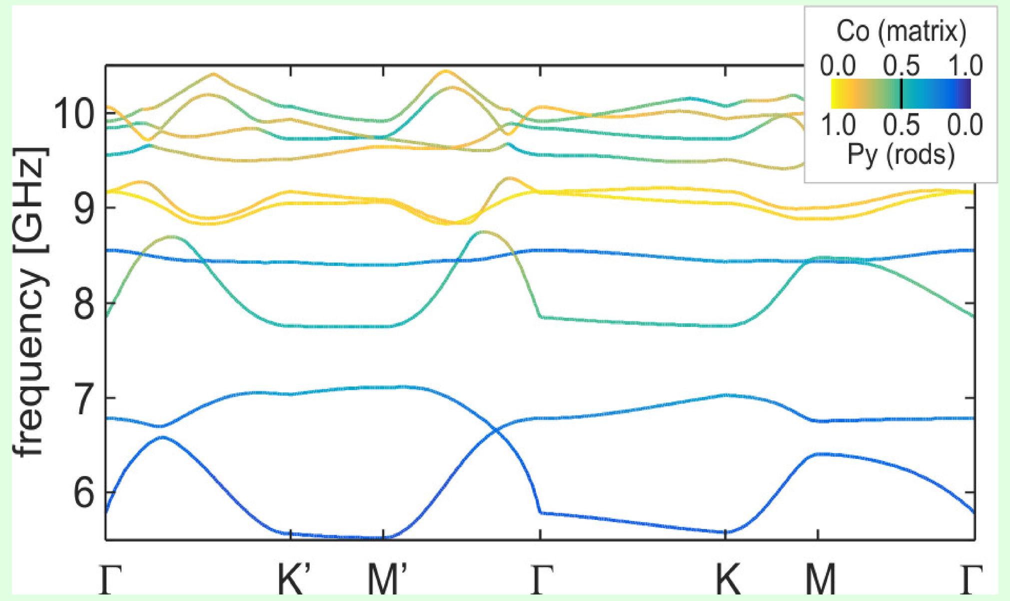

Fig. 5. Spin-wave spectra of Py/Co 2D MCs along the high-symmetry paths in the FBZ. Line colors depict the concentration factor according to the color scale shown in the inset. Three lowest modes are concentrated mostly in Co.

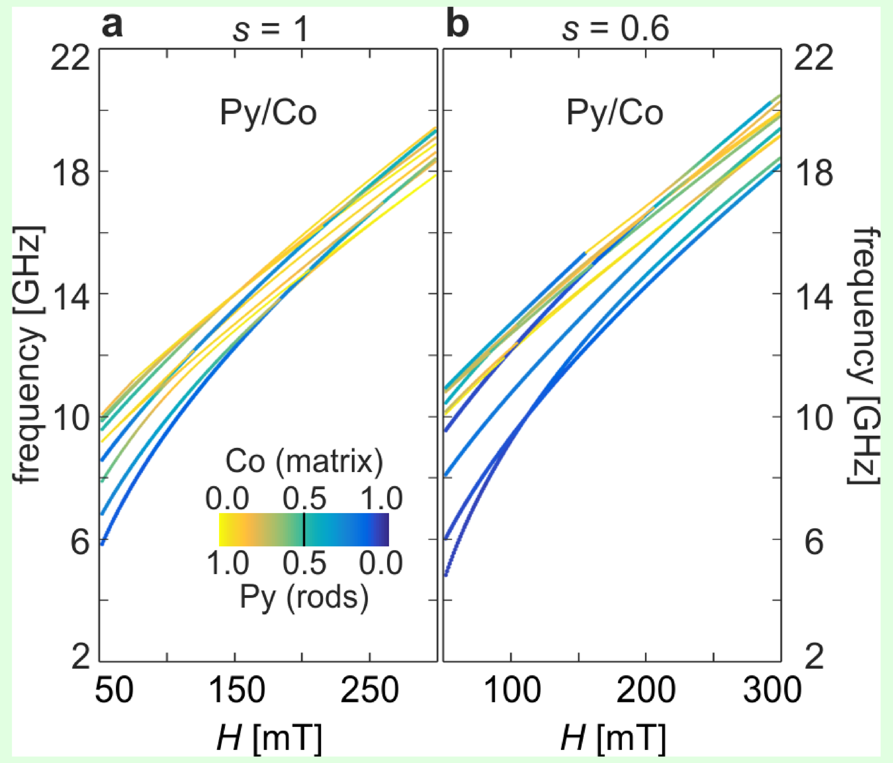

Fig. 6. Ten lowest frequencies of the spin waves vs. external field H calculated in the FBZ center (k = 0) for (a) s = 1 and (b) s = 0.6. Line colors – the same as in Fig. 2. Mode softening (right → left) = growing in-Co concentration.

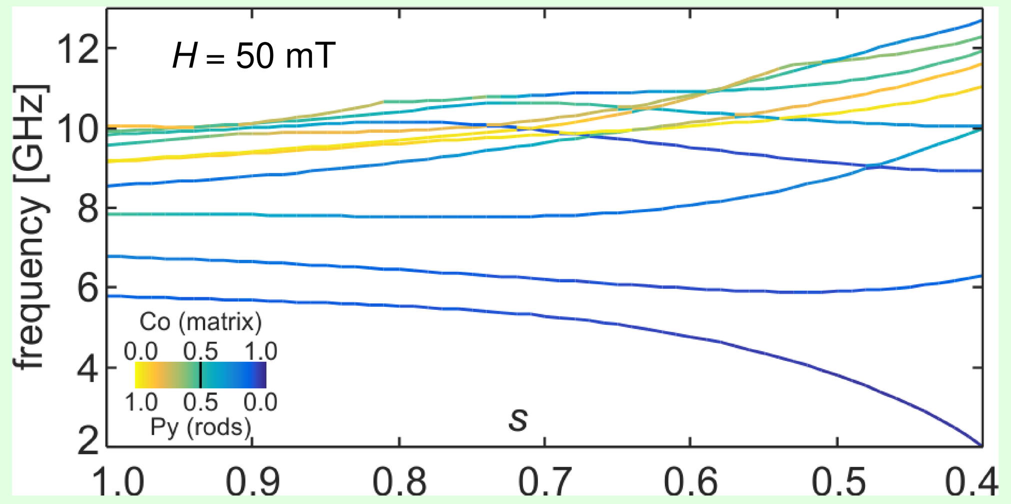

Fig. 7. Ten lowest frequencies of the spin waves vs. structure ratio s calculated in the FBZ center (k = 0) for H = 50 mT. Line colors – the same as in Fig. 2. Concentration in Co grows with squeezing.

Squeezing of the structure for Co/Py MCs

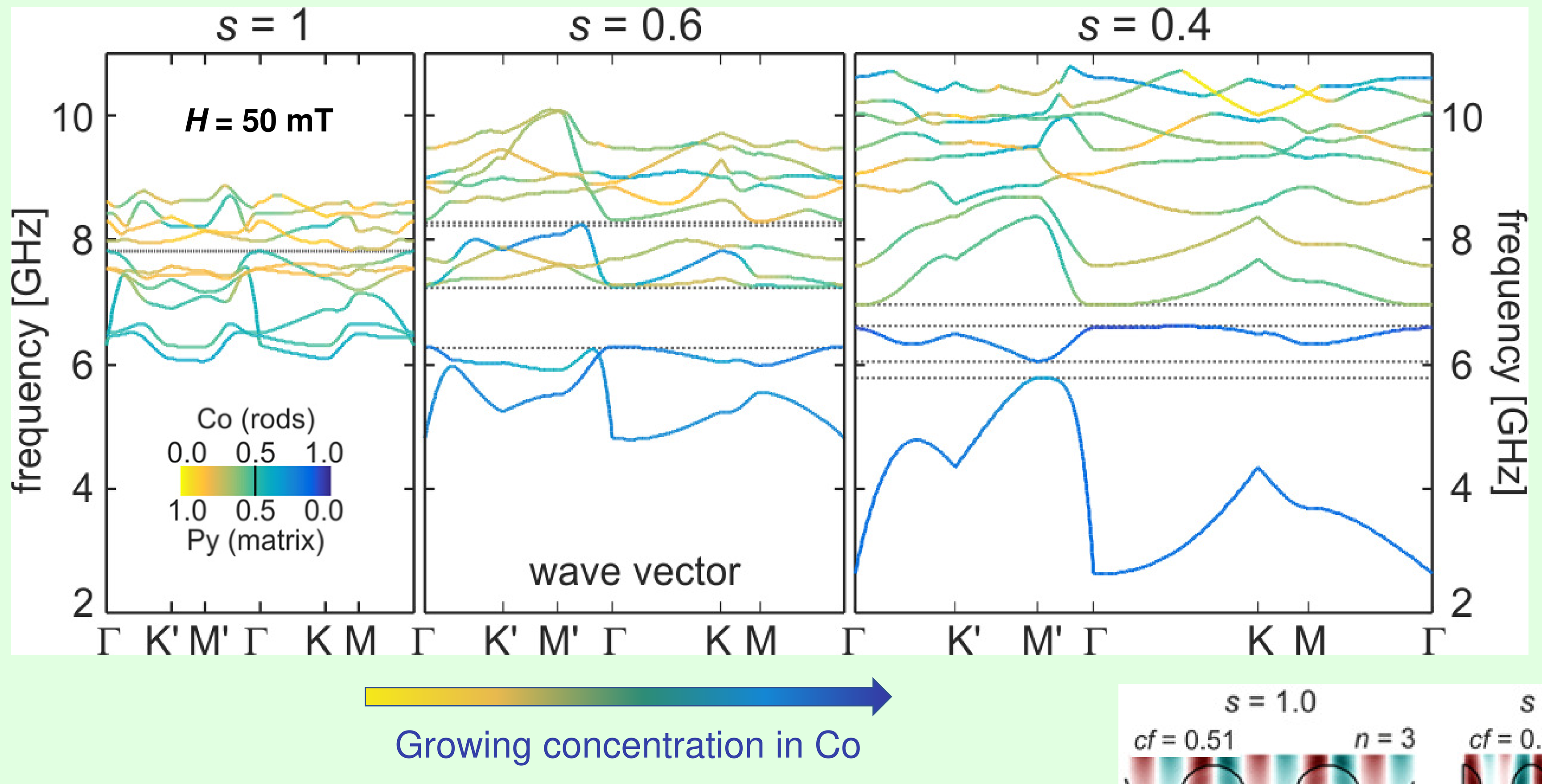

Fig. 8. Ten lowest modes of the spin-wave spectrum of squeezed Co/Py 2D MC vs. structure ratio s for the external field H = 50mT.

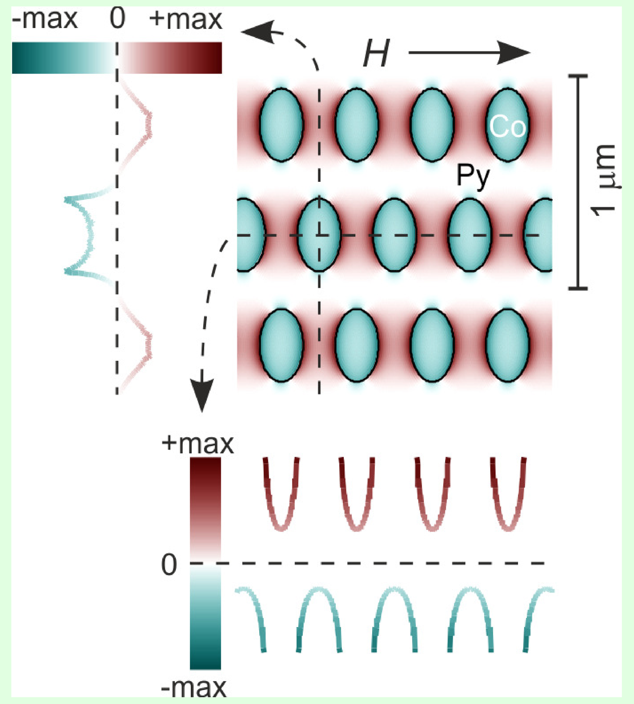

Fig. 9. Demagnetizing field for the squeezed Co/Py MC (s = 0.6) along with its cross-sectional profiles parallel (bottom) and perpendicular (left) to the external field H. Demagnetizing field in Co is negative.

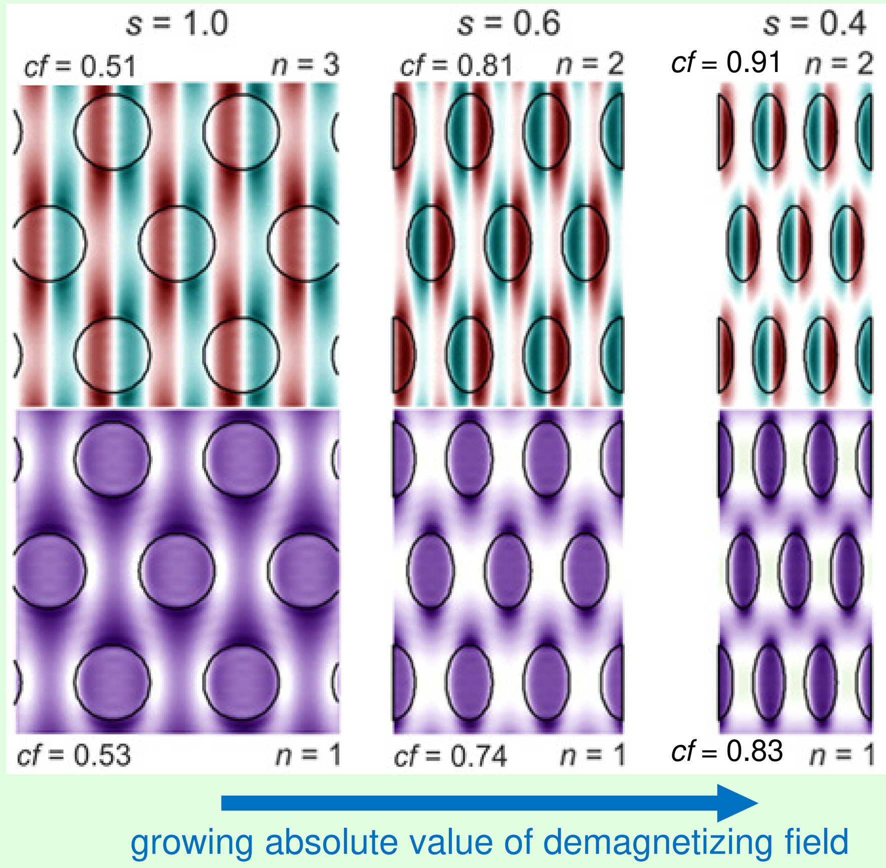

Fig. 10. Spin-wave profiles of two lowest modes vs. structure ratio.

Application – designing the response of the gap on the external field

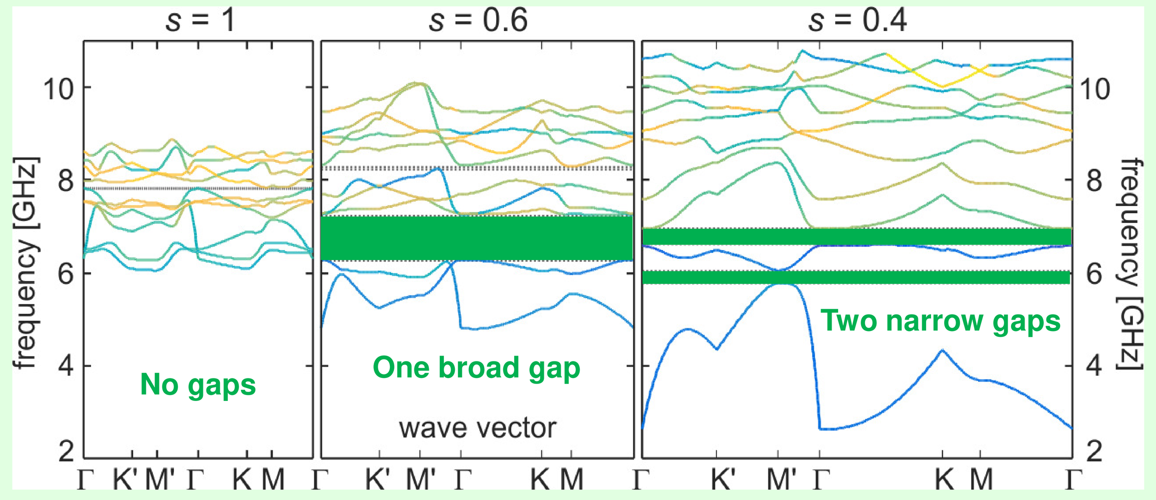

Fig. 11. Designing the gaps by the squeezing of the structure for Co/Py 2D MCs.

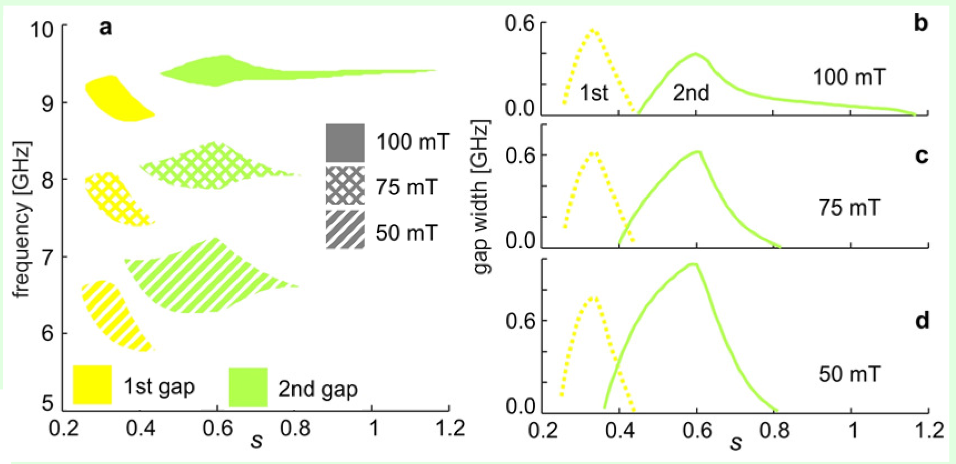

Fig. 12. (a) Two lowest band gaps vs. squeezing (structure ration, s) for Co/Py 2D MCs at three magnitudes of the external magnetic field. (b)–(d) The gap width evolution with s for band gaps presented in (a).

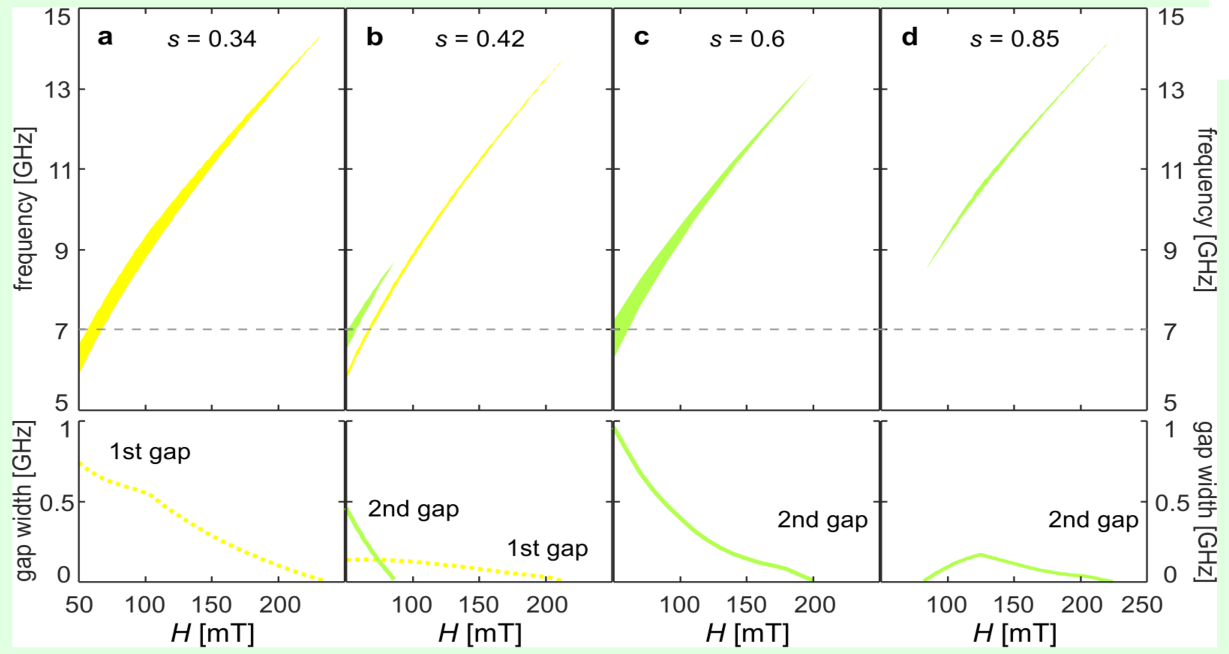

Fig. 13. Two lowest band gaps vs. the external field H for four structure ratios: (a) s = 0.34, (b) s = 0.42, (c) s = 0.6, and (d) s = 0.85. Below each graph, the dependence of the gap width on H is shown.