Magnonic crystals with modulated anisotropy

O. Wojewoda[1], L. Flajšman[2], I. Turčan[2], J. Petráček[1] and M. Urbánek[1,2]

FACULTY OF MECHANICAL ENGINEERING | institute of physical engineering

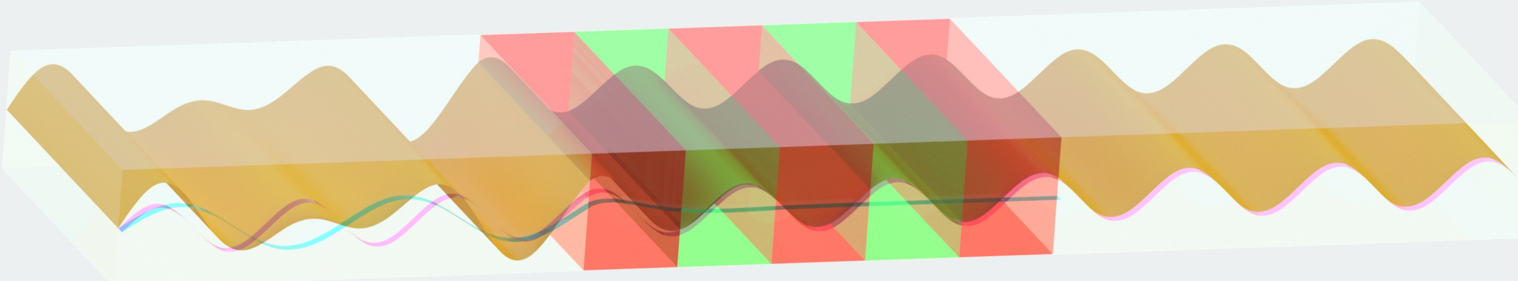
1 Institute of Physical Engineering, Brno University of Technology
Technická 2, 616 69 Brno, Czech Republic

2 CEITEC BUT, Brno University of Technology
Purkyňova 123, 612 00 Brno, Czech Republic

CEITEC NANO

Motivation

- Magnonic crystals promisses new possibilities in high frequency (GHz – THz) data processing.
- Frequency filters, logic gates, buffer elements have been presented in the framework of spin-wave based device
- The existance of a band gap is essential for controling the response of a magnonic device. This is commonly done by periodic modulation of some magnetic properties.
- We present approach of acquiring band gap with modulation of direction of uniaxial anisotropy in contrast with usualy used modulation of saturation magnetization, layer thickness or bias field.
- Controled modulation of direction of uniaxial anisotropy was experimentally observed on films fcc Fe films on Cu(100) substrate.
- The goal was to calculate dispersion relation of magnonic crystal by the means of micromagnetic simulation and analytical modeling.



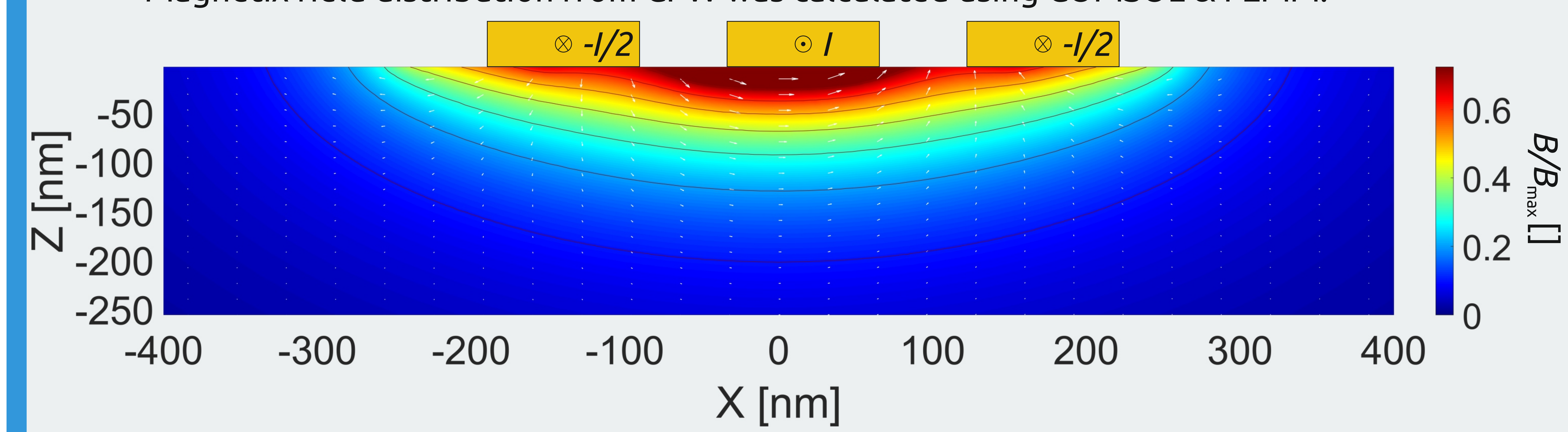
Frequency filter based on magnonic crystal with modulated direction of uniaxial anisotropy. In red and green regions direction of uniaxial anisotropy is modulated.

Micromagnetic simulations

- The dynamics of magnetization was calculated by means of micromagnetic simulations.

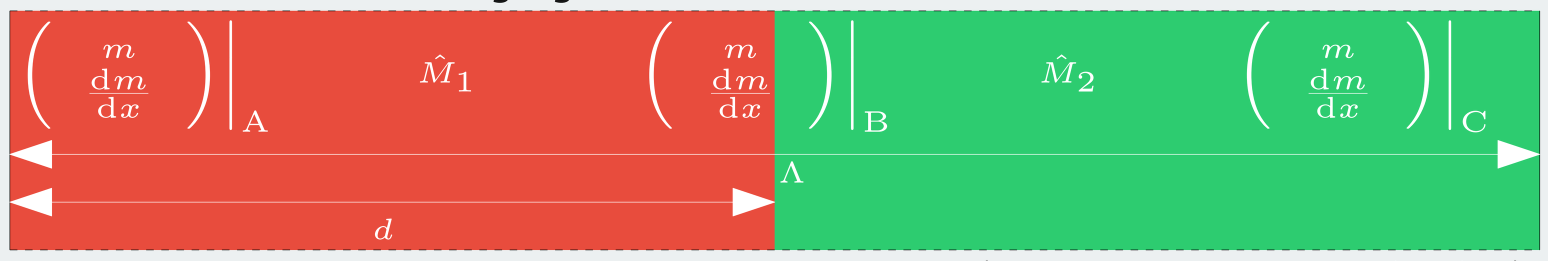
$$\frac{\mathrm{d}\vec{M}}{\mathrm{d}t} = -\gamma\mu_0\vec{M}\times\vec{H}_{\mathrm{ef}} + \frac{\alpha}{M_s}\vec{M}\times\frac{\mathrm{d}\vec{M}}{\mathrm{d}t}$$

- GPU accelerated finite difference solver MuMax[3] was used.
- Excitation of spin waves was done by Oersted field from coplanar waveguide (CPW).
- Magnetix field distribution from CPW was calculated using COMSOL & FEMM.



Analytical model

- The dispersion relation was obtained by transfer matrix method and general dispersion law.
- Magnetization and it's first derivative was considered to be continuos.
- Problem is reduced to finding eigenvalues of a transfer matrix.



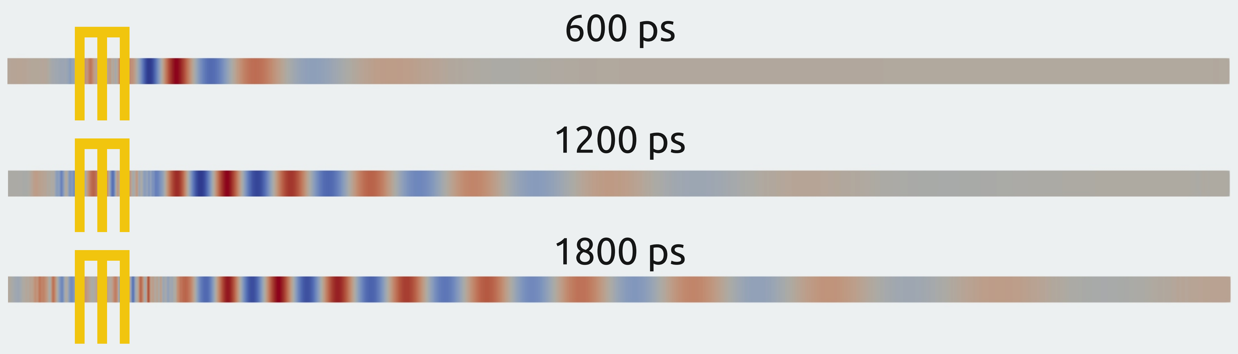
$$m = A\cos(kx) + B\sin(kx)$$
$$\frac{\mathrm{d}m}{\mathrm{d}x} = -kA\sin(kx) + kB\cos(kx)$$
$$\longrightarrow \hat{M}_{\mathrm{i}} = \begin{pmatrix} \cos(k_{\mathrm{i}}d) & \frac{\sin(k_{\mathrm{i}}d)}{k_{\mathrm{i}}d} \\ -k_{\mathrm{i}}d\cos(k_{\mathrm{i}}d) & \cos(k_{\mathrm{i}}d) \end{pmatrix}$$

$$\begin{pmatrix} m \\ \frac{\mathrm{d}m}{\mathrm{d}x} \end{pmatrix}\Bigg|_{\mathrm{A}} = \hat{M}_1\hat{M}_2\begin{pmatrix} m \\ \frac{\mathrm{d}m}{\mathrm{d}x} \end{pmatrix}\Bigg|_{\mathrm{C}} \qquad \begin{pmatrix} m \\ \frac{\mathrm{d}m}{\mathrm{d}x} \end{pmatrix}\Bigg|_{\mathrm{A}} = e^{\mathrm{i}\Lambda k_{\mathrm{FB}}}\begin{pmatrix} m \\ \frac{\mathrm{d}m}{\mathrm{d}x} \end{pmatrix}\Bigg|_{\mathrm{C}}$$

$$\hat{M}_1\hat{M}_2 - e^{\mathrm{i}\Lambda k_{\mathrm{FB}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = 0$$

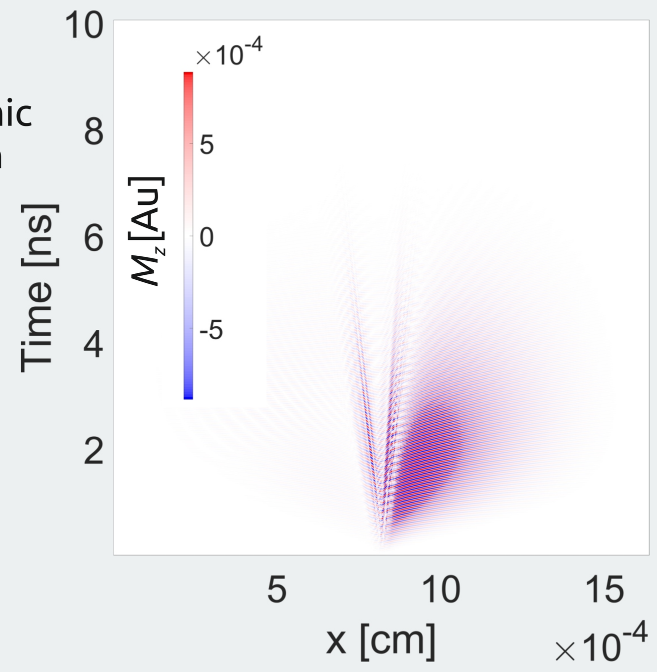
From magnetic simulation to dispersion relation

Micromagnetic simulation



Extract average along *y* axis and first 16 nm of *z* axis of m_z

- The time-spatial map of dynamic z-component of magnetization is extracted.

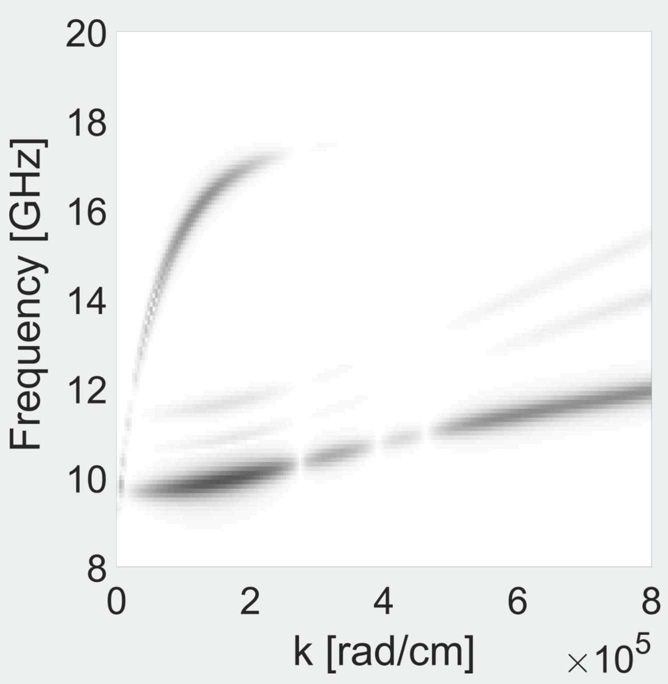


Windowing, detrend (deconvolution)

- Windowing and detrend improve result of discrete Fourier transform.
- The influence of exciting Oersted field is extracted using deconvolution.

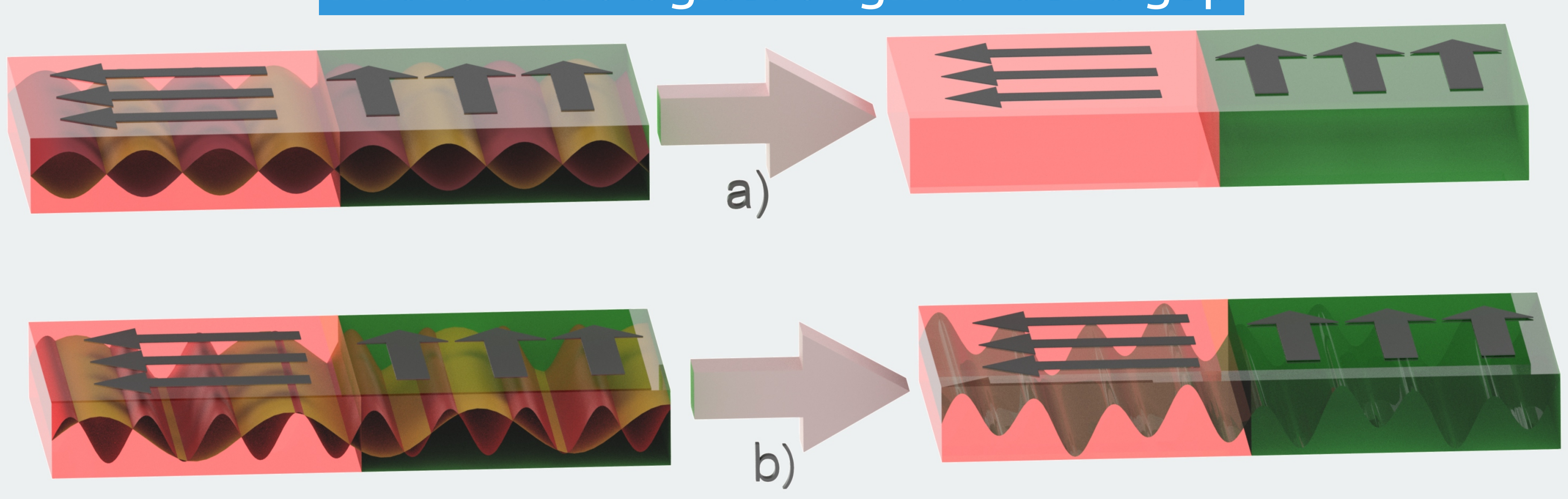
2D Fourier transform

- Dispersion relation was obtained by FFT of the time-spatial map.
- Black color indicates allowed modes.



Dispersion relation for infinite continous thin magnetic layer (Damon-Eshbach geometry).

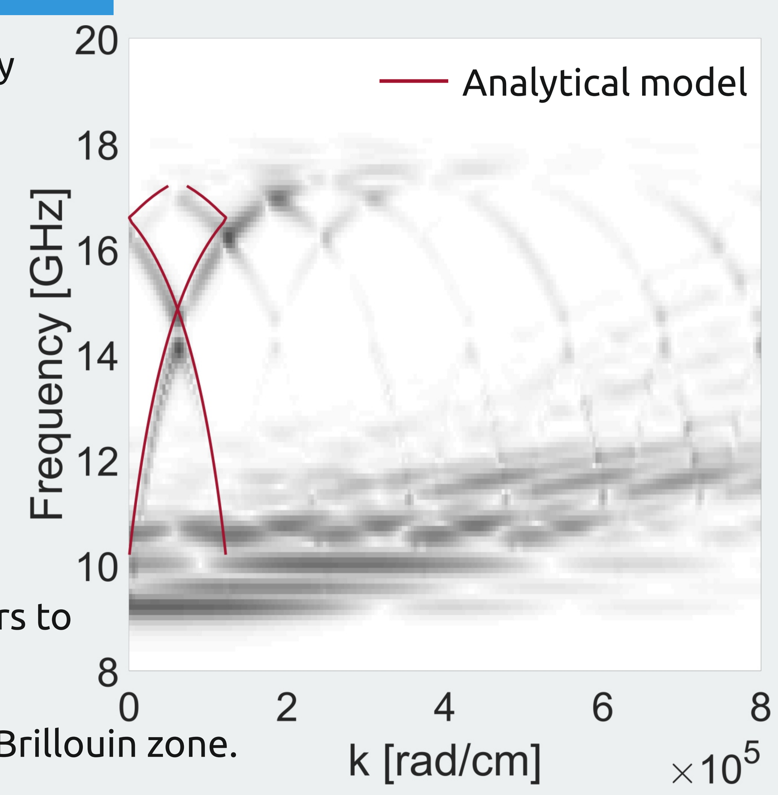
Phenomenological origin of band gap



a) When Bragg condition is fulfilled destructive interference occurs b) Allowed mode.

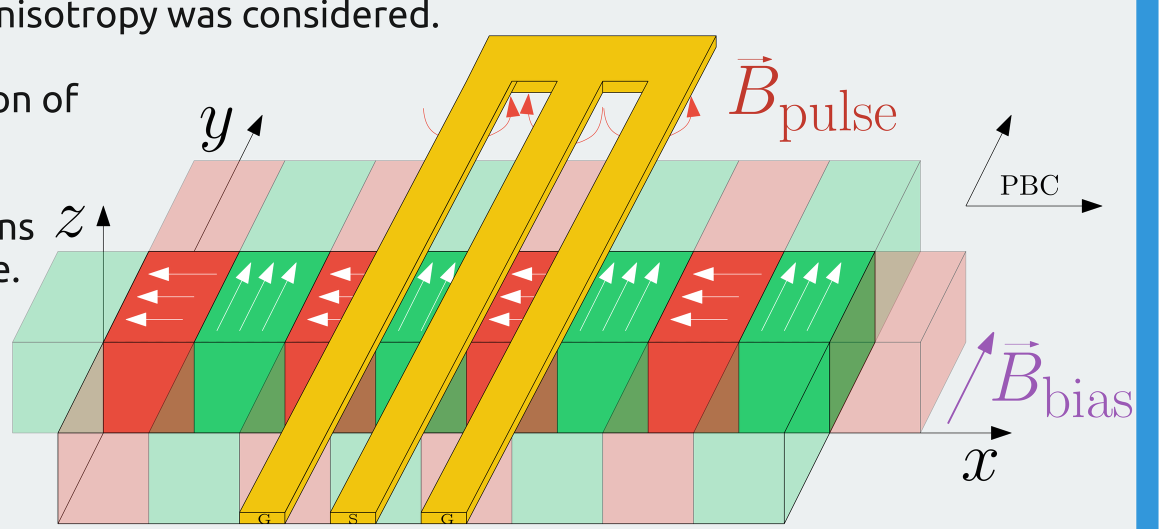
Results

- The periodic modulation of uniaxial anisotropy direction leads to the different dispersion relation, compared to the continous film.
- The creation of band gap together with complex band structure was observed.
- Whole structure can be controlled by external magnetic field.
- Brillouin zone width is inversly proportional to period.
- Modulation allows modes with higher *k*-vectors to be excited.
- Analytical model was calculated only for first Brillouin zone.



Geometry

- Thin film with modulated anisotropy was considered.
- Arrows indicate the direction of uniaxial anisotropy.
- Periodic boundary conditions were considered in *xy*-plane.
- Bias field – 100 mT
  Thickness – 64 nm
  M_s – 830 kA/m
  Pulse – 1 mT
  K_u – 6 kJ/m³



Conclusion

- The response of the continuous magnetic thin film and layer with modulated anisotropy was studied.
- Analytical solution is in agreement with micromagnetic simulation even for large *k*-vectors.
- The existence and the tunability of the band gap was confirmed for the structure with modulated uniaxial direction.
- Band structure is experimentally accsesible using Brillouin light scatering and electrically by vector network analyzer (VNA).

Reference

CHUMAK, A. V. Magnonic crystals for data processing. Journal of Physics D: Applied Physics

VENKAT, Guru, et al. Proposal for a standard micromagnetic problem: Spin wave dispersion in a magnonic waveguide. IEEE Transactions on Magnetics

Acknowledgemt

Part of this work was carried out with the support of CEITEC Nano Research infrastructure.

Ondřej Wojewoda | ondrej.wojewoda@vutbr.cz