Calculations of the FMR Spectrum in 1D Magnonic Crystals

M. Mruczkiewicz[1*], M. Krawczyk[1], V.K. Sakharov[2,4], Yu. V. Khivintsev[2,4], Yu. A. Filimonov[2,4], S. A. Nikitov[3,4]
[1]Department of Nanomaterials Physics, Faculty of Physics, Adam Mickiewicz University, Poznań, Polad
[2]Kotel'nikov Institute of Radio-engineering and Electronics of RAS, Saratov Branch, Zelenaya Str. 38, Saratov, 410019, Russia
[3]Kotel'nikov Institute of Radio-engineering and Electronics of RAS, Mokhovaya Str. 11, Bld. 7, Moscow, 125009, Russia
[4]Saratov State University, Astrakhanskaya Str. 83, Saratov, 410012, Russia
*m.mru@amu.edu.pl

Introduction:

FMR spectra of the periodic microstructures (one-dimensional magnonic crystals, 1D MCs) were obtained using COMSOL and results of these calculations were successfully compared with an experimental data for in plane magnetized MCs in Damon-Eshbach (DE, field parallel to stripes) and Backward-Volume (BV, field perpendicular to stripes) geometries. Experiments were performed using conventional FMR technique at constant frequency 9.85 GHz.

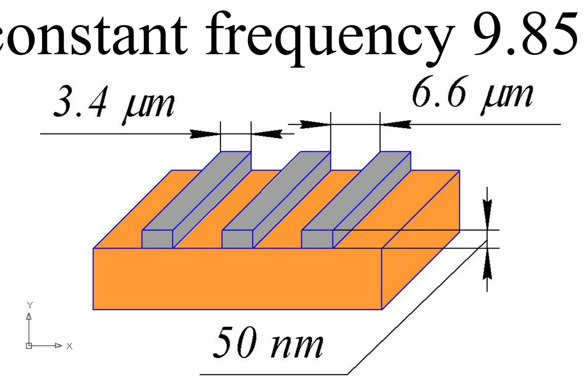

Figure 1. The structure composed of alternating 50 nm thick stripes of permalloy with 3.4 micrometers width.

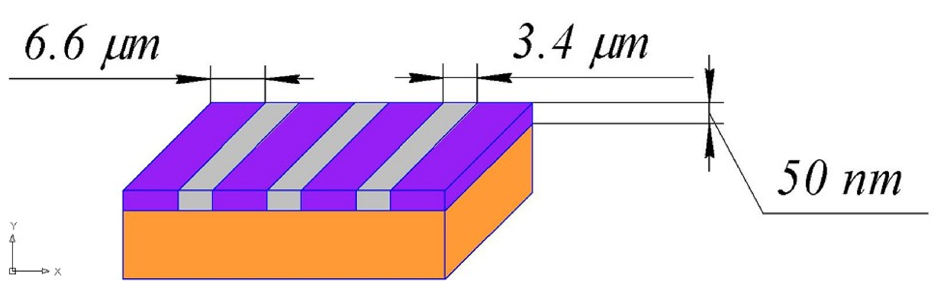

Figure 2. The structure composed of alternating 50 nm thick stripes of cobalt and permalloy with 6.6 and 3.4 micrometers width, respectively.

Computational Methods:

The Landau–Lifshitz equations:

$$\frac{\partial \mathbf{M}(\mathbf{r},t)}{\partial t}=\gamma\mu_0 \mathbf{M}(\mathbf{r},t)\times \mathbf{H}_{eff}(\mathbf{r},t)$$

Maxwell equations in magnetostatic approximation:

$$\nabla^2\psi=\frac{\partial m_x}{\partial x}+\frac{\partial m_y}{\partial y} \qquad \nabla^2\psi_{dem}=\frac{\partial M_S}{\partial z}$$

$\mathbf{M}(\mathbf{r},t)$, *Magnetization vector*

$\mathbf{H}_{eff}(\mathbf{r},t)$, *Effective magnetic field*

ψ, ψ_{dem}, *Magnetostatic potentials (dynamic, static)*

m_x, m_y, *Dynamic components of the magnetization vector*

M_S, *Static component of the magnetization vector*

Bloch theorem:

$$m_x=m'_x e^{i\cdot(\omega t+k_x x)}$$
$$m_y=m'_y e^{i\cdot(\omega t+k_x x)}$$
$$\psi=\psi' e^{i\cdot(\omega t+k_x x)}$$

The relative power of electromagnetic wave absorption in FMR:

$$P_k(\mathbf{r})=-\frac{1}{T}\int_0^T m_k^*(\mathbf{r},t)\cdot\frac{\mathrm{d}\mathbf{b}(t)}{\mathrm{d}t}\,\mathrm{d}t$$

$\mathbf{b}(t)$, *Time dependant external AC field*

T, *Period of variation of external AC field*

m_k, *Eigenvector solution, dynamic magnetization amplitude*

Geometry:

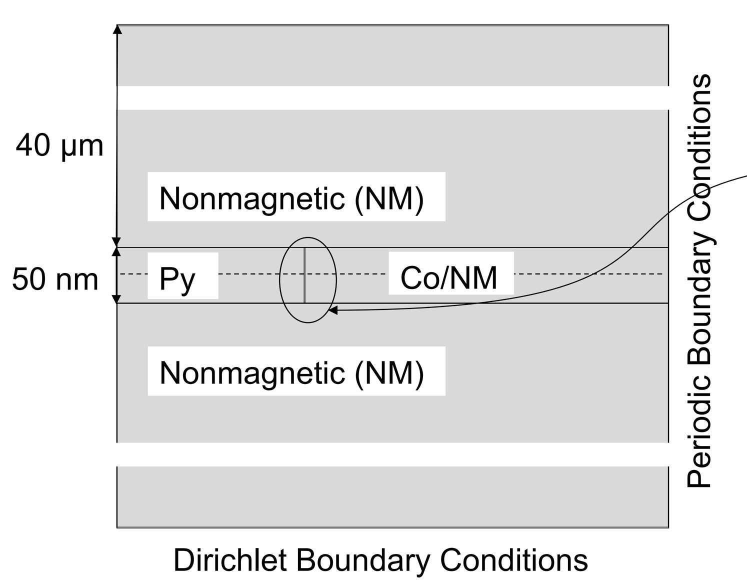

Figure 3. The geometry of the structure showed on figures 1 and 2.

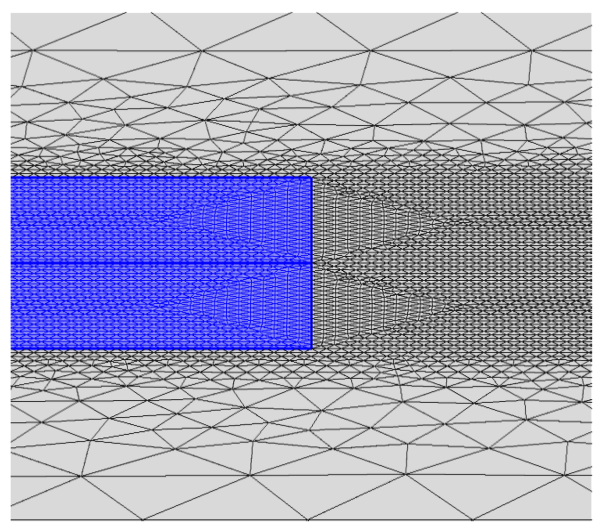

Figure 4. Mesh, distance between points within metalic ferromagnetic material varies from 1-3.5 nm in out of plane direction and between 4.5-14nm in plane direction.

Results:

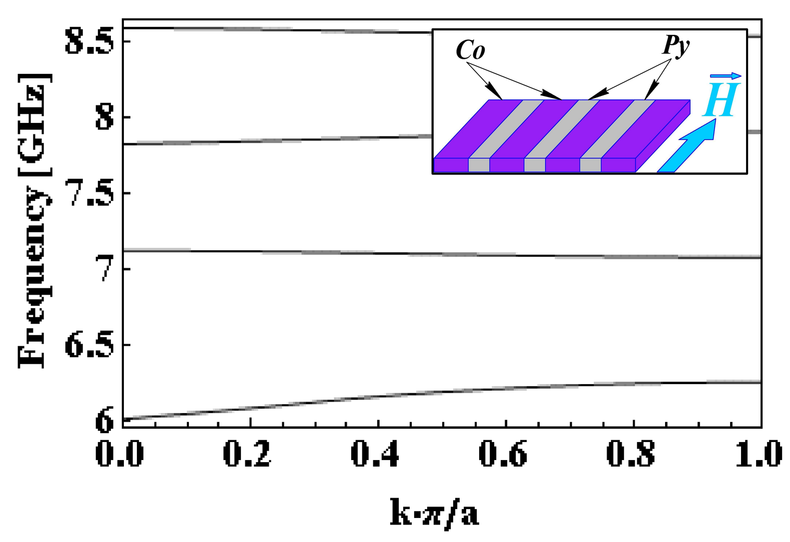

Figure 5 Dispersion Relation of MC in DE geometry (as shown in inset) at H_0=400[Oe]. The lattice constant a is 10 micrometers.

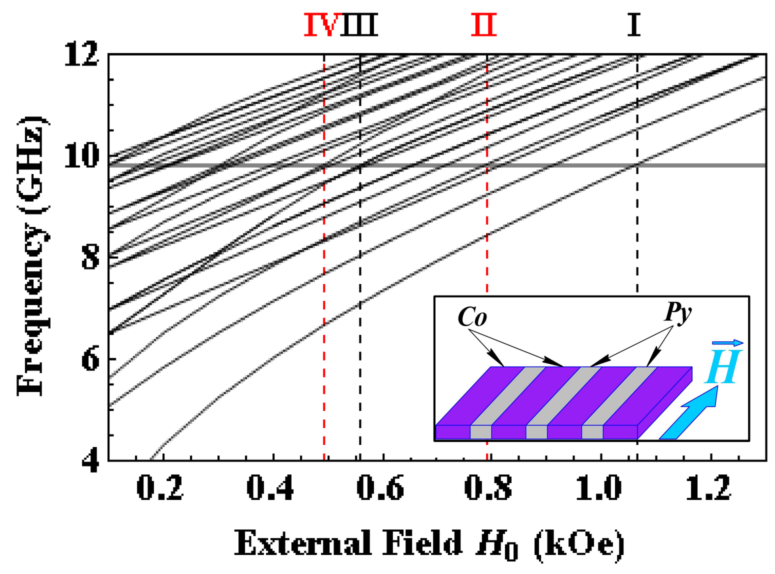

Figure 6. Field dependance of standing spin waves frequencies in DE geometry. Grid lines mark intensive FMR peaks.

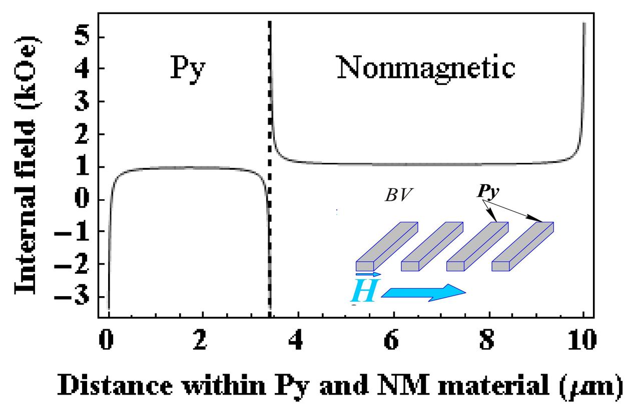

Figure 7 Internal field in Py stripes at the middle of the sample at H_0=1[kOe].

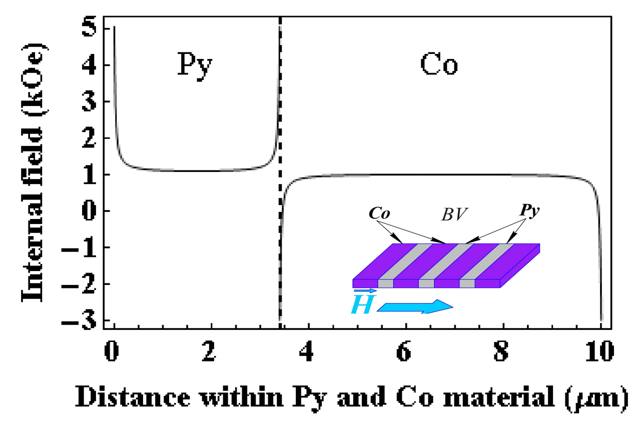

Figure 8 Internal field in Co/Py stripes at the middle of the sample at H_0=1[kOe].

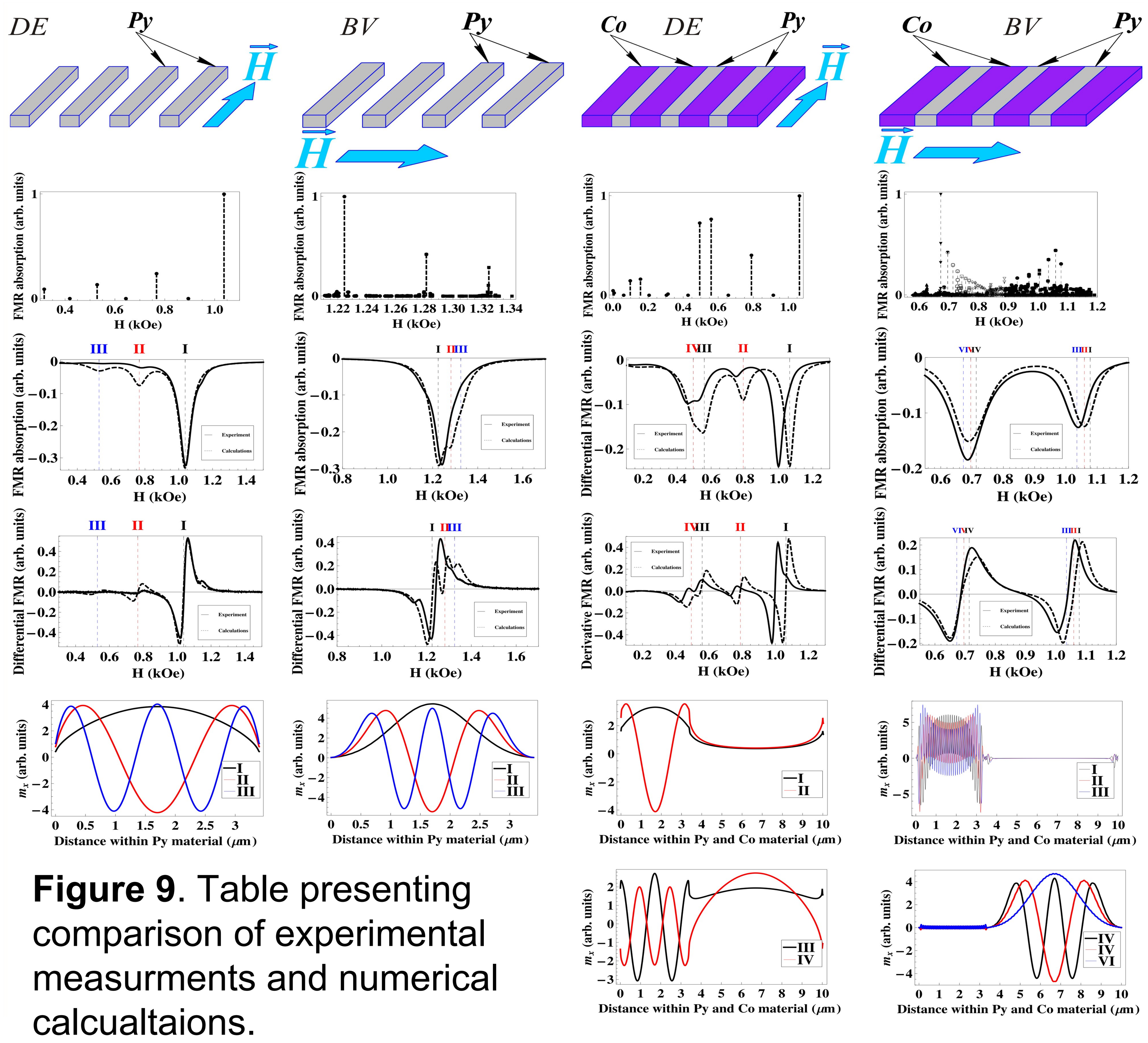

Figure 9. Table presenting comparison of experimental measurments and numerical calcualtaions.

Conclusions:

We have developed the method of calculation the FMR spectra in MCs with the use of partial differential equation interface. It has been applied to reproduce the measurement results in 1D MC composed of Co and Py stripes. The presented tool allows to analyze periodic structures with various geometries and material parameter compositions, being at the same time a tool that can serve for optimization and tuning the absorption of electromagnetic waves in ferromagnetic materials.

References:

1. Sakharov V. K., Khivintsev Y. V., Nikitov S.A., Filimonov Y.A. FMR investigation of magnonic crystals based on cobalt and Permalloy. International conference "Days on Diffraction 2012", Saint Petersburg, May 28 – June 1, 2012. – P. 166-167.
2. Sakharov V. K., Khivintsev Y. V., Nikitov S.A., Filimonov Y.A. Magnetic structures based on periodically alternating cobalt and permalloy stripes. International symposium "Spin Waves 2011", Ioffe Physical-Technical Institute. Saint-Petersburg, Russia, June 5-11, 2011. – P. 117.
3. Z. K. Wang, V. L. Zhang, H. S. Lim, S. C. Ng, M. H. Kuok, S. Jain, A. O. Adeyeye, Applied Physics Letters, 94, 083112 (2009).

Acknowledgments:

We acknowledge the financial assistance from the European Community's Sevenths Framework Programme (FP7/2007-2013) under Grant Agreement no. 247556 (People) for NoWaPhen project and under Grant Agreement no. 228673 for Magnonics project.
We acknowledge the Grant from Government of Russian Federation for Support of Scientific Research in the Russian Universities Under the Guidance of Leading Scientists (project No. 11.G34.31.0030)