

Review Report on PhD Thesis

Faculty: **Central European Institute of Technology
Brno University of Technology in Brno**

Academic year: **2020/2021**

Student: **Meena Dhankhar**

Doctoral study program: **Advanced Materials and Nanosciences**

Field of study: **Advanced nanotechnologies and microtechnologies**

Supervisor: **Ing. Michal Urbánek, Ph.D.**

Reviewer: **RNDr. Martin Veis, Ph.D.**

PhD thesis title: **Magnetic vortex based memory device**

Topicality of doctoral thesis:

The thesis aims to achieve the systematic control of both degrees of freedom in magnetic vortices, the polarity and the circulation, using electrical approach. The research field of magnetic vortices gain considerable attention in last two decades and several major breakthroughs were achieved (polarity and circulation switching, ns oscillators, etc..) motivated by applications in novel spintronic devices. However, there is no report about combined switching of polarity and circularity using electrical methods yet. Although the main research in the field of magnetic structures for information storage moved towards topologically protected spin textures, the manipulation of the spin alignment in patterned magnetic microdiscs can still help in the implementation of novel spintronic concepts into the practice.

Problem solving and dissertation results:

The thesis of 100 numbered pages consists of six chapters and two appendices. The topics of particular chapters were chosen carefully which resulted in a compact and fully informative text.

Following the introduction with motivation and description of thesis goals the second chapter contains the whole theoretical background necessary for the experimental techniques and discussion of obtained results. The chapter covers the complete theory of magnetic vortices, including the mechanisms of dynamic switching. Here I have to highlight a nice work of the applicant. The chapter is very well written adequately cited. Nearly 300 cited references to the literature also demonstrates a good erudition of the applicant. The third chapter is devoted to the description of used experimental techniques. These techniques covered magnetic force microscopy for static readout of vortex states, magnetic transmission x-ray microscopy at Berkeley synchrotron facility as well as the magneto-optical techniques. The main

part of the chapter was devoted to the original electrical approach for polarity and circulation readout based on anisotropic magnetoresistance.

Fourth chapter summarizes sample fabrication techniques, including all stages of the deposition and lithographic processes. It demonstrates tremendous amount of work which applicant had to do to successfully obtain large set of samples for further characterization.

The main results and their discussion are summarized in the fifth chapter. Here I have to point out a little bit chaotic ordering of the first part of the chapter. I am missing any deeper analysis of measured results and their explanation. In my opinion the applicant should link the results to the phenomena described in the second chapter a give the reader wider conclusion rather than only state that the results are in the figure. Also, some important values (disk size, thickness, etc.) “fell from the sky” and were not clearly justified based on the literature or previous experimental experience. The applicant has shown successful MFM readout of vortex polarity and circularity after the application of a current pulse and optimized Co/Pt multilayered structure to obtain large enough perpendicular magnetic anisotropy to control vortex polarity during switching. Here I am missing the comprehensive overview of magnetic properties of all prepared Pt/Co multilayers. Only the final multilayer is presented.

The second part of the chapter devoted to all electric control contains the main outcomes of the thesis. The text of this part is much clearer, and the discussion of the results is sufficient. The all electric control of the two magnetic vortex degrees of freedom was achieved with very high probability and repeatability.

Importance for practice or development of the discipline:

The results represent a significant step forward in the implementation of magnetic spin structures in novel spintronic concepts. It can have an impact on the further development in this field.

Meeting the goals set: The goals of the thesis were achieved.

Formal adjustment of the thesis and language level:

The dissertation proves the ability and readiness for independent activity in research or development or for independent theoretical and creative artistic activity. The dissertation includes original and published results or results accepted for publication and meets the conditions specified in § 47 paragraph 4 of the Act. The thesis is well written in English language with minimal grammar errors and misprints. The thesis clearly describes all activities of the applicant during her doctoral studies and contains original and partially already published results.

Questions and comments:

I have several questions for applicant:

- 1) In the theoretical part I didn't find any information about the magnetic shape anisotropy and its influence of the vortex core dynamics. Can the applicant give a brief overview how the shape anisotropy influences the vortex?
- 2) How the temperature influences the vortex dynamics? Are there some reports about temperature assisted vortex switching in magnetically hard materials?

- 3) In the Fig. 5.2c only one magnetic vortex changed the circulation to the initial position. How one can explain the remaining two vortices where the circulation didn't change?
- 4) On page 54 there is a statement "The rise time and fall time of the applied pulses play a crucial role in switching polarity and circulation." Can the applicant explain this in more details?
- 5) Figs. 5.3. and 5.4 show the results on which sample from Table 5.2?
- 6) What was the magnitude of out-of-plane field in experiments described in section 5.2.2?
- 7) Can the applicant describe changes of the peak shape in rectified voltage spectra with respect to the magnetic field in terms of the vortex evolution stages?

Conclusion:

Despite the minor drawbacks described above the presented thesis is a solid piece of scientific work which clearly present the ability of applicant to fulfil all requirements for independent individual scientific research. In my opinion, the reviewed thesis fulfill all requirements posed on theses aimed for obtaining PhD degree. This thesis is ready to be defended orally, in front of respective committee.

In Prague, date 15.3. 2021

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RNDr. Martin Veis, Ph.D.