Review Report on PhD Thesis

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

Academic year: **2020/2021**

Student: **Ing. Marek Vanatka**

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

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

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

Reviewer**:** **Dr. Sebastian Wintz**

PhD thesis title: **Static and dynamic properties of nanostructured magnetic materials**

Topicality of doctoral thesis:
By this thesis, Mr. Marek Vanatka reports the results of his research on the static and dynamic properties of nanostructured magnetic materials conducted at Ceitec Brno.
The thesis is divided into six chapters. The introductory chapter provides both motivation and theoretical background for the investigated phenomena. In particular the two central topics of the thesis-magnetic vortices and spin waves in thin films-are reviewed in a very detailed and comprehensive manner. Chapters number two and four introduce the main experimental methods applied in this work: LTEM and MTXM high-resolution magnetic microscopies, electrical AMR detection, sample fabrication, and detection of spin dynamics using a VNA (thoroughly described in chapter four, including its application to FMR, vortex dynamics and spin-wave spectroscopy). There are three separate chapters reporting the main results achieved (chapters three, five and six).
Chapter three deals with the investigation of vortex nucleation processes, identifying three different size-dependent nucleation states (c-state, two-vortex state, buckling state) using a combined approach of LTEM/MTXM direct imaging and micromagnetic simulations. It is further demonstrated that also AMR detection can be used to determine the specific nucleation state without the need for complex imaging techniques.
In Chapter five, propagating spin-wave spectroscopy is applied to determine the spin-wave dispersion relations and the decay lengths of NiFe, CoFeB and YIG films of various thicknesses. For that purpose, the propagation of spin waves over different distances between transmitter and receiver is probed and subsequently analyzed, leading to very clear and convincing results. By investigating the gap openings of the fundamental mode at avoided crossing points with perpendicular standing waves, it was possible to directly estimate surface pinning effects.

The final chapter introduces a freestanding and positionable microwave antenna device as an optically addressable alternative to conventional antennas typically patterned directly onto the sample under test. Proof-of-principle operation of such devices is successfully demonstrated for BLS, FMR and propagating spin-wave spectroscopy (excitation and detection).

In my view, all three results sections (vortex nucleation, inductive spin-wave spectroscopy, freestanding microwave antenna) are highly topical to the field of magnetism and spintronics. In particular, I would like to highlight here the significant contributions made by Mr. Vanatka to the field of magnonics with respect to the electrical determination of spin-wave dispersion relations and the subsequent estimation of surface pinning effects.

Meeting the goals set:
As to the level they are defined in the thesis, Mr. Vanatka has achieved all attainable goals successfully.

Problem solving and dissertation results:
Throughout the thesis, referencing, experiments, calculations and analysis are conducted rigorously. The conclusions drawn and the results reported are scientifically sound.

Importance for practice or development of the discipline:
By means of this thesis Mr. Vanatka is making valuable contributions to the fields of magnetism and spintronics. From the content, Mr. Vanatka has already published two articles as first author in highly-ranked journals, with another manuscript being in preparation. At the same time, he also has made more than five contributions to international conferences.

Formal adjustment of the thesis and language level:
The thesis is clearly written and at a high level of English language, in particular for a non-native speaker.

The study is duly completed by a state doctoral examination and the defense of a dissertation, which proves the ability and readiness for independent activity in research or development or for independent theoretical and creative artistic activity. The dissertation must include original and published results or results accepted for publication.

Questions and comments:

- Comment: The thesis is often phrased in plural ('we'/'our'/'us'). I believe this is a good way to acknowledge the contributions made by other people this work. Nevertheless, it can be sometimes ambiguous to which parts of the work were done by the author and which parts were done by others. Therefore, I recommend to add a short paragraph somewhere (or to each chapter) for clarifying these individual contributions.

- Question 1: Vortex nucleation states

Is there an influence of the dominating perpendicular field component in the TEM on the nucleation process? How does the merging of the two vortices (two-vortex state) and the three perpendicular entities (buckling state) actually happen according to micromagnetic simulations? Do the two cores in the two-vortex state have to have always opposite polarities?

- Question 2: FMR using VNA

Is electrical shorting of the CPW an issue in the flip-chip geometry when measuring metallic samples and if yes, how to avoid it? Why does the n=1 PSSW have a different absorption curve shape than the FMR and what could be the reason for why higher order PSSWs (n≥2) are not observed by the VNA yet in BLS?

- Question 3: Spin-wave spectroscopy and mode hybridization

Was it possible to directly observe PSSWs in the propagating spin-wave spectroscopy and if not, what could be a possible reason for that? The observed gap opening is attributed to mode hybridization and in particular its magnitude to surface pinning effects. Could similar gap opening magnitudes also be realized when the hybridization of more than two modes was considered (multimode hybridization) instead of surface pinning? On page 87 it is stated that modes of even and odd numbers n may not hybridize. Was this actually calculated and would it mean that such modes can actually cross each other in the dispersion relation (instead of exhibiting avoided crossing points)?

Conclusion:

In my opinion, the reviewed thesis fulfills all requirements posed on theses aimed for obtaining PhD degree. This thesis is ready to be defended orally, in front of respective committee.

Dresden, March 29th 2021

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