The presented thesis deals with manipulation of antiferromagnetic (AFM) moments and fabrication of AFM semiconductors, two of the frontier research topics in condensed matter physics. The thesis is clearly organized and easy to navigate between chapters. The first topic, AFM spin manipulation, is further divided into manipulation by exchange spring effect, cooling AFM moments in external field and current induced AFM moment manipulation. The results of the current induced AFM moment manipulations, being the main result of the presented thesis, have been recently published in Physical Review B[1]. Mgr. Helena Reichlová has also contributed to 12 other works published in high-impact journals, namely e.g. Nature Communications, Physical Review Letters or Applied Physics Letters. The scientific quality of the work is undoubted.

In spite of high quality of the presented work, I have several questions, comments and remarks which I would like to be answered or commented.

- The torque $T$ acting on a magnetic moment $m$ is said to be defined in equation (2.2). This is not true. Torque is defined as $T = r \times F$, where $r$ and $F$ is a position vector and force acting on a magnetic moment, respectively. The formula (2.2) is then derived from definition taking into account energy of magnetic moment in external magnetic field ($E = -m \cdot B$) and force being negative gradient of energy.

- The term ”training effect” is used without prior definition on page 16.

- Abbreviation ”XMCD” is used without prior definition on page 16.

- Can you give more detailed description of spin Hall effect (SHE) and spin galvanic effect (SGE)? It is not clear from description on page 17-18, what is exactly the difference between SHE and SGE.

- Could you explain Fig. 2.11 (e), spin Seebeck effect (SSE) in more detail? Why SSE is not rather spin polarization on two opposite sides of the sample provided the temperature gradient is perpendicular to the spin gradient? Please, see Fig. (1) for illustration. Also, according to inverse spin Hall effect, the electrical field should be measured also in a direction perpendicular to the spin gradient. Hence, the SSE depicted in Fig. 1 should merge the ordinary Seebeck effect.

- What would be anomalous spin Seebeck effect?

- Can you explain in more detail how spintronic devices will decrease electric power consumption and why they are going to be faster than standard electronic devices? What is going to make antiferromagnetic spintronic devices even faster than the ferromagnetic ones?

- Description of Figure 2.12, left and right notation is exchanged.

- page 37, MgO layers have been deposited in pure Ar atmosphere. What is gas purity? How do you control MgO layer thickness?

- How do you grow AlO$_x$ protection layer? Is it atomic layer deposition or thermal oxidation of aluminium or any other technique?
Some samples or layers are said to be grown in external magnetic field up to 0.4 T. How this field is achieved? Is it set of permanent magnets? Why also annealing has to be performed in external magnetic field?

There is IrMn 2.5 nm thick layer in Fig. 3.12 (c), however, there is no such data in Fig. 3.14. Why?

I have several questions regarding Figs. 3.13 and 3.14. It can be understood from the text in the following chapters that there is a distinct region depicted in green color in Fig. 3.14, I mean the only-broadening region. However, it is not very convincing from data in Fig. 3.13 that this region actually exists (in comparison with depicted size of the green region drawn in Fig. 3.14). The main question is following. Since the only-broadening region is considered (based on data shown later), why the broadening-and-shift region (exchange spring effect) is so large (the blue region in Fig. 3.14)? It can be clearly seen in Fig. 3.13 that the whole high-temperature and high-thickness data (within the blue region) have very small or almost negligible broadening. This part is therefore much more similar to only-shift data (grey region). Can you provide arguments why the data are categorized as in Fig. 3.14? Have you tried to categorize the data in Fig. 3.13 quantitatively (K-means, K-medoids, Singular-Value-Decomposition or Non-negative Matrix Factorization)? It would be helpful to show all the raw data which were taken into account for the analysis in Fig. 3.13-3.14.

page 48, what is real importance of the tunnelling barrier in TAMR measurements? What would be a problem if the barrier was thermionic or if there was no barrier at all (eg. bulk dominated space charge limited current)?

It is claimed on page 48, that the non-linearity is seen in \( \frac{dI}{dV} \). It is then concluded that this is a sign of tunnelling. What I-V characteristics is expected in the low-bias tunnelling regime? The high-bias I-V characteristics can be certainly non-linear, however, why the non-linearity is attributed to tunnelling? Can you exclude other effects (eg. thermionic emission, space charge limited current or their combination)? There are also missing units in Fig. 3.15 (right).

What kind of magnet did you use in experiments depicted in Fig. 3.16? Was it superconducting (SC) coil or resistive magnet? If the SC coil was used, how did you make corrections on remanent field?

The two experiments are compared in Fig. 3.16, TAMR and SQUID signals. Can you comment on almost order of magnitude different broadening measured by these two methods in Fig. 3.16 (c) and (d)? Why the coercivity measured by SQUID is only negative in Fig. 3.16 (e) and it is both positive and negative in Figure 3.16 (f). Isn’t this the effect of remanent field in SC coil?

The difference between TAMR and SQUID results is discussed in terms of effective probed areas. Can you provide more quantitative comparison of these areas and estimate, whether it can really bring up to order of magnitude difference of broadening measured by TAMR and SQUID?

The term "field cooling" is used on page 45 without prior explanation and with no reference to the following text. It is explained later in the chapter 3.5 though.

Demagnetizing field has been introduced in the thesis, however, it is not discussed anywhere throughout the text. Can you discuss demagnetizing field particularly in the case of in-plane and out-of-plane field cooling in Figure 3.21 and also the rotational dependence of magnetization (magnetization does not follow exactly external out-of-plane magnetic field, chapter 3.6)?

Appendix A.2.1, it is claimed that many devices have been measured, can you be more specific?

Appendix A.4, PPMA is probably typographical error, shouldn’t it be PMMA?

page 100, double vector product should be in parenthesis. Diadic product can be without parenthesis.

References are inconsistent. There are missing pages at some publications. The journal names should be either full names or abbreviations, not both randomly (eg. Ref. 62, 70, Phys. Rev. B and Ref. 83, Physical Review B).

There are few more typographical errors, eg. y-axis label in Fig. 2.10 (c) as the most visible one.

English is satisfactory, however, there is Czech word order sometimes (e.g. page 29, "In a large number of modern computers data are recorded and stored..." ) and directly translated Czech phrases (e.g. page 44, ”on the other side” (na druhou stranu), should be "on the other hand".)
In spite of all the comments and questions I have I find this thesis very well written, up-to-date, dealing with frontier research in condensed matter physics and very important for development of spintronics, manipulating magnetic moments in antiferromagnets, progress in a growth of novel antiferromagnetic semiconductors and allowing broad scientific community to follow this progress. I am aware of the novelty of the presented data and effects studied here, hence I consider my questions rather as points for discussion than criticism. I would like to point out that the main results of this work have been already published in high-impact journal, Physical Review B [1], where the data, analysis and whole interpretation has been already reviewed in a strict peer review process. I recommend this dissertation for public defense.

References


Date: 12.11.2015
Referee: RNDr. Jan Kunc, Ph.D.