Annex No. 10 to the MU Directive on Habilitation Procedures and Professor Appointment Procedures

HABILITATION THESIS REVIEWER'S REPORT

Masaryk University	
Applicant	Mgr. Ondřej Caha, Ph.D.
Habilitation thesis	Thin films of topological insulators
Reviewer	RNDr. Martin Veis, Ph.D.
Reviewer's home unit, institution	Faculty of Mathematics and Physics, Charles University

The habilitation thesis of Ondřej Caha with the title “Thin Films of Topological Insulators” offers a comprehensive summary of the basic physics of topological insulators with emphasis on their thin films. It covers the theoretical underpinnings of topological insulators, their unique electronic structures, as well as the experimental methods employed for their analysis, such as X-ray scattering, X-ray absorption spectroscopy, angle resolved photoemission spectroscopy and others. From the material point of view, it covers various aspects of bismuth chalcogenide thin films and the effects of their magnetic doping by manganese. Another group of materials, which are introduced in the thesis are narrow bandgap semiconductors (Pb,Sn)Se and (Pb,Sn)Te, classified as topological crystalline insulators. Their physical properties are discussed in detail with respect to doping.

After short preface where the candidate introduces himself the first chapter sets the stage for the thesis, outlining the focus on topological insulator thin films, particularly Bi_xTe_y and (Pb,Sn)Se or (Pb,Sn)Te thin films, and the exploration of doping in these materials. It also highlights the author's contributions to the structural characterization of the materials.

In Chapter 2 the author briefly describes the theory of topological insulators. He pedagogically builds their complete picture, starting form topological invariants, topological Hamiltonians, and the explanation of topologically protected surface states. He logically connects these quantities to experimentally measurable phenomena, such as quantum Hall effect, spin polarized photocurrents or Kerr and Faraday effects. Afterwards the applicant introduces two main groups of materials, which were the subject of the research. Firstly bismuth chalcogenides and their magnetic variations, and secondly topological crystalline insulators (Pb,Sn)Se or (Pb,Sn)Te. In both cases the topological properties of these materials are described in connection with their crystal structure and its symmetry.

Chapter 3 of the thesis briefly overview several experimental methods used by applicant for the thorough structural and electronic characterization of the materials. Starting from basics of Xray scattering with emphasis on thin films with randomly alternating motifs to reciprocal space mapping. Other structural analysis methods, such as X-ray absorption spectroscopy and transmission electron microscopy are mentioned as well. Separate section is afterwards devoted to angle resolved photoemission spectroscopy, which became over the years a standard tool to display k-resolved electronic structure of the materials and surface states.

Chapter 4 contains nine reprinted selected papers with the description of author's contribution. I appreciate applicant's honesty and statement that the structural analysis interpretation in paper 5 is not entirely correct.

Finally, chapter 5 summarizes the thesis and outlines possible future research in the field mentioning artificial heterostructures for better control of magnetic order in magnetic materials, or for combination with ferroelectric materials.

From the formal point of view the thesis is very well written with high quality figures and large number of references, which reflects the candidate's pedagogical qualities and capabilities. The publication track of the applicant is appealing, including publications in leading journals in the field. Although it might look that the experimental methods which applicant used are just common characterization tools without no real impact on the discussion of topological properties of materials, this is not the case. Proper analysis of structural order is absolutely crucial for correct discussion of the experimental results from subsequent experiments. This makes applicant's contributions extremely valuable. The quality, originality of the results, and the level of their comprehensive analysis and discussion reflects to the applicant's ability to contribute to cutting-edge scientific research in the field of condensed matter physics.

The applicants CV also proves his international experience via two long term stays in USA and his success with grant applications. The bibliographic indicators are also above average. There is no doubt that the candidate has clearly demonstrated the competence for a successful habilitation procedure.

Reviewer's questions for the habilitation thesis defence (number of questions up to the reviewer)

- In the section 2.4 is stated that the surface states related Kerr and Faraday rotation can be measured on topological insulators. Since the incident light is not sensitive only to the surface, but also to bulk the measured signal will be mixture of these two contributions. I was wondering if there is some effective experimental approach how to separate the contributions from surface states to Kerr/Faraday rotation. Could the applicant comment on that?
- In the conclusions the applicant mentions appearance of the piezoelectric field in PbSnSe material when doped, which leads to Z_2 topological insulator. I didn't find a detailed description of this phenomenon in the thesis. Could the applicant comment on that?
- Section 3.1.5 demonstrates experimental results of phase transition of (Sn,Ge)Te layers. Is this material a topological insulator? Otherwise, what was the motivation to study this interesting compound.
- Regarding magnetic topological insulators. How does the topological behaviour change when the material is antiferromagnetic or altermagnetic (new group of collinear antiferromagnets)?
- What are the future plans of the applicant? Is he planning the research on artificial heterostructures as outlined in the chapter 5?

Conclusion

The habilitation thesis entitled “Thin films of topological insulators” by Ondřej Caha **fulfils** requirements expected of a habilitation thesis in the field of Condensed Matter Physics.

Date: 15.12. 2023 Signature: