Assessment of doctoral thesis

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Doctoral study program: **Mechanical engineering** at CTU in Prague, FME

Field of study: **Mathematical and physical engineering**

Title: **Charge carrier transport in conjugated polymers with controlled morphology**

Supervisor at CTU in Prague: **doc. Ing. Petr Vlčák, Ph.D.**

Supervisor – specialist at CERN: **Dr. Vincent Baglin**

Workplace: **Conseil Européen pour la recherche nucléaire (CERN), Geneva, Switzerland**

A. Relevance of the chosen topic and level of analysis of the current state of the art

The submitted work investigates the electron irradiation-induced emission of electrons and gas molecules, and thermally controlled gas adsorption and desorption at cryogenic temperatures from surfaces of technical metals and special coatings. Influence of the selected key physical parameters on these processes is experimentally tested and theoretically evaluated, and role of these mechanism on technically relevant applications discussed in detail. A special attention is paid to the influence of these processes on the operation of the large hadron collider (LHC) in CERN.

Despite the extensive research devoted to the mentioned topic, there is still a number of unresolved problems resulting from the complicated, multi-parametric and strongly correlated nature of the analyzed processes. A comprehensive and detailed overview, exhaustively describing the current state of knowledge in this field is on 38 pages provided in the Chapter 2 - State of the Art of the thesis.

The subject of the submitted dissertation is highly topical and internationally significant. Fully adequate analysis of the current state of the art is provided.

B. Content of the dissertation and its structure, formal aspects of the work

Content of the dissertation written in English at very good language level, with acceptable level of typos (e.g., pp. 23: “Figure [57]”; pp. 29: “Figure [8]”; pp. 121, Fig 5.28: the aC layer thickness shown in the inset of the left panel does not agree with the figure caption text; pp. 157: “δ_{max} and δ_{max}”; pp. 163, paragraph 6.2.3, 3rd sentence: the mentioned ESD and SEY values seems to contradict to the courses shown in Fig. 6.3 and Fig. 6.5). The text is largely based on 4 papers (reprints of 3 of them published in respected international impacted journals, where the author is the first author are enclosed at the end of the text) and 4 conference contributions of the author. The numbered text consists of 236 pages. It starts with abstract, acknowledgement, list of abbreviations and symbols, and Introduction, it continues with six numbered chapters, and is concluded by “Summary and conclusions” part, list of the author’s publications, bibliography (332 references), Appendix (providing additional information about uncertainty analysis methods used and performed experiments), author’s CW, and reprints of the three first-author papers.

The Chapter 1 – "Motivation and objectives" provides basic information about the accelerator complex in CERN, physical conditions in LHC with emphasis on factors influencing the ultra-high vacuum (UHV) level, and relevance of the studies focused on electron cloud built-up, electron stimulated desorption (ESD) and related dynamic vacuum effects for other technical applications.

The Chapter 2 – "State of the Art" summarizes in nine paragraphs the current knowledge in the areas related to the issues under study: general aspects of electron interactions with a surface, evaluation of secondary electron yield (SEY) and its characteristics for different surfaces, description of electron-stimulated gas desorption processes from a surface and overview of the key parameters that apply here, specification of effects caused by cryosorbed gasses, and description of temperature programmed desorption (TPM) method application in their characterization.

The Chapter 3 – "Research objectives" focuses first to provide a narrower definition of the thesis research area, then explicitly and soundly formulates in four points the dissertation objectives, and finally estimates its expected impact.

The Chapter 4 – "Experimental methods and instruments calibration" introduces the novel setup and methodology used in retrieval of the experimental data, gradually presenting its main parts.

The Chapter 5 – "Results and discussion" is the key part of the dissertation. On 63 pages, the results split in six thematic areas are overviewed, discussed and compared with the available results (if any) of different research groups. The areas involve characterization of the studied surfaces, SEY and ESD of technical-grade metal surfaces, functional coatings and crysorbed gases, and TPD of the latter. Influence of individual physical parameters on the studied effects is examined and discussed, including in particular the dependence on electron energy, dose and sample temperature, role of the surface composition, morphology, and optional prior surface conditioning, and angular emission analysis.

The Chapter 6 – "Application of research findings" focuses primarily on attempt to formulate semi-empirical theoretical parametric rules describing the obtained results, combining the methods introduced in Chapter 2 with all the new datasets referred in the Chapter 5. A particular attention is payed to the discussion of the derived rules' application in the development of CERN LHC experimental system.

Despite the considerable amount of the research conducted, the structure of the dissertation is logical and clear. The text is mostly well formulated and readable, and provides a comprehensive description of the methodological procedures applied and the results achieved. Some rare ambiguities are the subject of the questions in the part "F" of this review. Formally, the text of the thesis is very carefully prepared, with a minimum of typos, and fulfils all the requirements laid on the dissertation theses.

C. Chosen methods and solution procedures and appropriateness of their application

The experimental setup and methodology used in collection of the data, described in detail in the Chapter 4, is top-notch in the field, fully adequate to the stated research objectives. As stated in the "Summary and conclusions" part, built-up and preparation of the system to the measurements were done with a crucial contribution of the author. Careful testing and calibration of the system performed prior and during experiments allowed for a reliable data collection and subsequent

uncertainty analysis of the acquired data, contributing thus significantly to the reliability of the obtained results and their predicting power. Adequate additional methods (SEM, XPS) were used in basic characterization of the composition and morphology of the studied samples.

The instrumentation, methods and approaches applied were appropriate to the performed research and adequate to the planned objectives of the dissertation.

D. Achieved results and their theoretical and practical importance

A large number of time-consuming experiments was performed during the PhD project and a large set of valuable results (published in respected international journals and conference contributions) obtained, presented in a systematic way in Chapter 5, further discussed and compared with theoretical models in Chapter 6, and summarized in the section „Summary and conclusions".

As the most valuable practical achievement of the thesis I consider the successful built and commissioning of the novel, cutting-edge experimental setup allowing a precise characterization of electron- and thermally-stimulated desorption processes from different surfaces under well-controlled experimental conditions.

From the theoretical point of view, the acquired data and their analysis provide a significant contribution to the steady effort towards construction of a realistic model capable of prediction of dynamic vacuum evolution in systems / surfaces exposed to influence of electronic and thermal excitations at cryogenic temperatures.

The results achieved in the thesis represent an internationally significant contribution to the recent applied vacuum and surface science research, with a high theoretical as well as practical importance, particularly relevant to the field of accelerator technology.

E. Dissertation objectives and their fulfilment, evaluation of the candidate's expertise in the field

All the stated dissertation objectives were successfully fulfilled. Performing all the presented research tasks, the candidate has confirmed beyond any doubt his high expertize in the fields relevant to the performed research.

F. Questions and comments on the content of the dissertation

In respect to the dissertation content, I would like to ask the following questions and ask the candidate to answer them

- On pp. 87, a setup is described used to measure sample surface temperature by Pt1000 thermometer. How was the resistance of the leads corrected? Was a 4-point method used?
- Fig. 5.6 shows correlation plots to experimental SEY and E_{max} points. How were the shown linear fits marked by dash lines constructed?
- On pp. 108, in the commentary text to the desorption courses shown in Fig. 5.13, it is mentioned that the ESD yield is ca. linearly proportional ($\eta \sim E^1$) in the energy region up to E_{max}. Is it really so?
- Experimental data marked in Fig. 13 and 14 by points show local maxima at ca 10 eV ignored by the fits. What effect are the maxima related to?

- Fig. 5.38 shows SEM images of REBCO layer samples. Was any additional method used to prove that the surface nano-irregularities are really crystalline in sense of its internal structure? In the related text, their Ba-Cu-O composition is then proposed. Is this proposition backed by any experimental analysis/data?

G. Final evaluation

The submitted dissertation represents an original contribution to the investigated topic significant on an international scale, and clearly demonstrates the prerequisites of the candidate for independent creative scientific work.

I recommend the thesis for defense and in case of its success I propose to award Michal Haubner with the scientific degree of Ph.D.

In Kamenice, July 9, 2023

doc. Ing. Ladislav Kalvoda, CSc.

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