CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING

Břehová 7, 115 19, Praha 1

Review of the PhD thesis entitled:

"Novel Schemes in Ion Acceleration Driven by High-Intensity Lasers"

by the thesis supervisor **doc. Ing. Jan Pšikal, Ph.D.**

Author: **Ing. Martin Matys**

Supervisor Specialist: **Prof. Sergei Bulanov**

PhD thesis and the work of the author

The content of the thesis is a result of doctoral study and research at the Department of Physical Electronics of the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University (CTU) in Prague and at the Department of Radiation Physics and Electron Acceleration at Extreme Light Infrastructure ERIC. Laser-driven ion acceleration is investigated worldwide for more than twenty years from the first demonstration of accelerated protons with energies of a few tens of MeV from a thin foil towards advanced acceleration regimes and targets. These new regimes and advanced targets are being developed with the aim to enhance acceleration efficiency and / or to improve various parameters of the accelerated ions. Since the most intense laser pulses focused on the targets are very short (in tens or hundreds of femtoseconds), numerical simulations are indispensable tool for the explanation of various phenomena related to the laser-target interaction and resulting ion acceleration, as well as for new proposals and predictions of achievable ion energies with future laser technology. That is also proved by the work of the author and his main outputs in the thesis based on the analysis of the performed multidimensional particle-in-cell simulations of femtosecond laser pulse interaction with various target designs.

The main original results of the author were published in several research papers in relatively highly impacted journals (New Journal of Physics, Plasma Physics and Controlled Fusion, …) and have been summarized in a review paper in Photonics. Martin Matys was the main and corresponding author of three papers (including the review paper) and he significantly

contributed to two papers in impacted journals as an important co-author. He also participated on other projects not included in this thesis, e.g. the project Directed High Energy Radiation and Particle Beams Generated Using Extreme Magnetic Fields supervised by Dr. Georg Korn at the side of ELI Beamlines. He collaborated with groups from TAE Technologies, Inc., Ecole Polytechnique, University of Szeged, and ELI-ALPS on simulation studies of proton and deuteron acceleration using mJ-Class few-cycle high-repetition lasers for neutron generation. A part of his work has been devoted to other activities related to the teaching, IT network administration at CTU, popularization of science, miniprojects for secondary school students, and to SPIE CTU in Prague Student Chapter as a chapter officer. These activities and the review process of two submitted papers complicated to finish his dissertation in the planned schedule, so it was submitted about almost two years later. On the other hand, Martin has gained new interesting experiences, above the level of average PhD student.

Description and evaluation of the thesis

The PhD thesis consists of five chapters. The main aim of the thesis is rather general – theoretical study of novel schemes of laser-driven ion acceleration, available via the use of high-intensity laser pulses, with the help of particle-in-cell (PIC) simulations. These schemes should advance ion acceleration in the sense of improving the generated ion beam properties like lowering its divergence or/and achieving higher maximal ion energy. As described in the introductory part (the first chapter), three main topics are studied to improve the ion acceleration in the frame of the author's work: (1) the employment (and combination) of different acceleration mechanisms, (2) the use of special target geometry and composition, (3) the shaping of laser pulse profile. The second chapter discussed most important terms and plasma parameters used in the thesis, which is followed by the review of laser-driven ion acceleration mechanisms investigated in the theoretical research of the author. The third chapter deals with methods used for this research, namely particle-in-cell simulations, data post-processing and visualization. The third chapter briefly describes particle-in-cell method and the code EPOCH used by the author for his numerical calculations in the frame of the thesis. Here, I appreciate the author's effort for visualisation of the results to be more attractive to the public. The fourth chapter summarizes results achieved by the author during his PhD study which were published in five scientific papers. Five sections in this chapter comments on the results presented in each paper, the contribution of the author, and on other dissemination of the results by the author (at scientific conferences etc.). The fifth chapter summarizes the results and introduce future plans for the work of the author.

In my opinion, theoretical part of PhD thesis provides a solid basis to better understand the authors' results presented in detail in scientific papers and summarized in the thesis. Methods used are described quite briefly, but they were described in more detail in previous works of the author as explained in the third chapter. The quality and originality of the author's work can be proven by the number of accepted publications in his record, all of the publications included in the dissertation were published after standard peer-review process. In order to publish the results, the author had to convince all referees about the topicality of his research, the originality of his results as well as about the correctness of his methods, outputs and conclusions. As I was mostly involved in this process, I can confirm that the author worked independently, collaborated with his supervisors and other researches and used experience and specialization of them in an efficient way. I also appreciate that some of the authors' ideas (e.g., ultrathin targets with plasma shutter) were already tested to be manufactured due to author's collaboration with staff at CTU.

Summary

PhD thesis submitted by Martin Matys has brought sufficient amount of novel interesting results, especially those related to the application ultra-high laser pulse intensities to efficient ion acceleration with specially designed targets. These main results were also published in relatively highly impacted scientific journals in the field. Therefore, it can be concluded that the candidate proved his ability for independent and original scientific work of a high level and his work fulfills formal requirements for the doctoral dissertation.

I therefore strongly recommend Martin Matys for the award of PhD degree subject to the successful oral defense.

In Prague, 3rd March 2023 doc. Ing. Jan Pšikal, Ph.D.