Evaluation report

on a thesis for the educational and scientific degree PhD
in professional field of Physical science (4.1),
on defense procedure at the Faculty of Physics (FzF)
of Sofia University "St. Kliment Ohridski" (Sofia University)

The review is prepared by: Assoc. prof. Ekaterina Iordanova, Institute of Solid State Physics - BAS, as a member of the scientific jury according to Order No РД 3895/21.02.2023of the Rector of Sofia University

Topic of the thesis: Conversion of CO2 using Arc Discharges at Atmospheric Pressure
Author of the thesis: Vladislav Ivanov

I. General description of the submitted materials

1. Information about the submitted documents

The candidate Vladislav Valentinov Ivanov has submitted a thesis and an Author's abstract, Autobiography, Author's reference for the contributed publications, copies of diplomas for the degrees Bachelor and Master, copies of published scientific works, as well as the mandatory tables for the Faculty of Physics taken from the Regulations on the Conditions and Order for Acquiring Scientific Degrees and Occupying Academic Positions at St. Kliment Ohridski Sofia University.

The submitted documents by the candidate meet the requirements of the the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria and the Regulations for its Regulations, as well as the Regulations on the Conditions and Order for Acquiring Scientific Degrees and Occupying Academic Positions at Sofia University.

2. Details of the applicant

The candidate Vladislav Ivanov is a full-time doctoral student at the Department of "Radiophysics and Electronics", at the Faculty of Physics of the Sofia University "St. Kliment Ohridski". He received his bachelor's (2016) and master's (2018) degrees at the Department of Radiophysics and Electronics of SU "St. Kliment Ohridski", majoring in "Communications and Physical Electronics". In addition, he also qualified as a physics and astronomy teacher at the same university. Professionally demonstrates experience as a software developer for visualizations and simulations, in-depth knowledge of various programming and Markup languages, experience with Desktop and web technologies, as well as application software. From 2022 to present, he is also a visual effects (VFX) and fluid dynamics simulation software

developer. He participated in five national and international specialized forums, in two research projects, as well as in author teams of four refereed and indexed scientific publications for the period 2021-2023.

3. General characteristics of the candidate's scientific achievements

The candidate's thesis is presented in 125 pages and contains an introduction, 3 chapters, a conclusion, a bibliography including 84 references, as well as a list of participations in specialized forums, the figures and tables used.

The presented scientific achievements of the candidate are mainly in the field of plasma discharges with a specific focus on the study of DC discharges operating at atmospheric pressure and powers < 1000 W, with applications for carbon dioxide dissociation. The main objectives of the dissertation are presented in a justified and motivated manner.

The first chapter presents an overview of the achievements in the field to date. A description of the different types of DC discharges is presented. This is followed by an overview of the modeling of plasma processes at the macroscopic level. A summary of the main characteristics of the carbon dioxide molecule and the specifics of its dissociation is presented, as well as the historical development and implementation of experimental research related to the use of carbon dioxide dissociation through plasma discharges.

The second chapter details the developed computer fluid model of the cross section of the positive column of a magnetically stabilized arc discharge. The used numerical model was applied to the studied configuration of a low-current arc (below 1 A) operating under direct current conditions, in an argon gas flow and atmospheric pressure. The use of argon gas in the model is motivated and substantiated with the emphasis of the dissertation work on carbon dioxide. The research presented in this chapter is published in Article B.1 of the list provided.

Chapter three deals with the specific experimental work based on results in the study of the dissociation of carbon dioxide. The experimental setup and used discharge configurations are described in detail, as well as the well-structured methodology of the experimental studies. In a separate section (Results and discussion) relevant analyzes and obtained results are presented in detail. In addition, a wall-stabilized arc discharge plasma installation in a cylindrical tube is also presented. These additional studies have been used to help achieve a more precise measurement of the dependences of dissociation and energy efficiency on gas flow and discharge mode. It is noted that this additional task would allow the work on the current thesis to potentially be continued in the future. The results presented in this chapter are published in articles B.2 and B.3 of the provided list.

In the conclusion, the conducted theoretical and experimental studies of low-current gliding discharges, the main results and contributions of the thesis, as well as the personal ones of the candidate, are well-summarized.

Scientific works:

a) the scientific publications included in the thesis are a total of 3, such as 2 publications from Group I with quartile Q1, 1 article from Group II with Q 2. In all three publications, the candidate is the first author and they were published in the period 2021-2023. The presented scientific publications meet the minimum national requirements and, accordingly, the additional requirements of SU "St. Kliment Ohridski" for acquiring the educational and scientific degree "doctor"/PhD in the relevant scientific field and professional direction;

b) the scientific publications included in the dissertation work do not repeat those from previous procedures for acquiring a scientific title;

c) there is no proven plagiarism in the submitted dissertation and abstract.

4. Scientific and scientific-applied achievements

The main goals and objectives of the presented dissertation work are related to the investigation of the properties of low-current DC discharges with a magnetically stabilized and sliding arc, using a configuration with flat diverging electrodes, and under atmospheric pressure conditions. The applicability of carbon dioxide dissociation under the specific conditions is clearly presented, as well as the theoretical studies supporting their validation for different types of gas media.

The research activity includes the computer modeling of a magnetically stabilized arc discharge and its experimental investigation with laboratory experimental setups including sliding arc discharges (without magnetic stabilization) as well as magnetically accelerated discharges. The objectives set in the dissertation work are clearly formulated and defined in four categories based on: 1. The creation of a two-dimensional computer model of a section of the positive column of a magnetically stabilized arc, in the conditions of a constant electric field, at atmospheric pressure in argon, and current 50 − 400 mA; 2. The implementation of an experimental setup, including a high-voltage electrical supply, a gas discharge device for testing arc discharges at atmospheric pressure, water cooling and other components; 3. Carrying out a series of experimental studies on a set of discharge configurations, at atmospheric pressure and low currents; and 4. The study of the behavior and properties of the discharge at low currents (< 200 mA), as well as an analysis of the mode of operation of the discharge.

The scientific contributions of the goals are demonstrated and supported by 3 scientific publications - two from Group I (Q1) and one from Group II (Q2), with the candidate being the first author in all three. The results are presented with 3 reports at international forums.

The dissertation presents theoretical and experimental studies of low-current slip discharges, in cases of (i) magnetic stabilization and (ii) without stabilization, related publications [B.1, B.2, B.3]. The presented work is divided into two main parts describing in detail the study of (1) the used numerical model of a low-current arc discharge and (2) the experimental study of the properties of several types of low-current arc discharges for the case of carbon dioxide dissociation.

A two-dimensional fluid model is presented and developed for the cross-section of the positive column of an arc or glow discharge, creating a non-equilibrium plasma, at atmospheric pressure. The essential results have been achieved after conducting a series of computer simulations allowing the study of DC arc discharge with magnetic stabilization. The influence of the magnetic field on the charged particles was analyzed, and it was established that the effect of magnetic stabilization is achieved when the magnetic force is compensated by the frictional force between the arc and the gas flow. The developed fluid model is also used to (i) find the ranges of gas velocities in which magnetic stabilization can be achieved; (ii) different stable and unstable regimes of low-current magnetically stabilized arcs, in a gas flow transverse to the arc current, are identified; (iii) basic characteristics of a magnetically stabilized arc in gas flow are obtained; (iv) values for the friction force and the effective coefficient of friction of the arc with the gas stream are determined, as well as an estimate of the effective radius of the positive column of the arc. The obtained results convincingly demonstrate the contributions in the theoretical part of the dissertation work, which also determine the potential for their use in different from the studied conditions of gas environments.

The main contributions and results achieved in the experimental research part are related to: (i) Investigation and evaluation of different configurations of sliding and stabilized arc discharges, with application to carbon dioxide dissociation; (ii) Confirmation of the effect of transverse instability in a magnetically stabilized arc in a gas flow predicted by the simulations with the developed numerical model; (iii) Establishing that the discharge can operate in both glow and arc modes after qualitative analysis of the discharge mode with respect to cathodic processes, for currents ≤ 100 mA, at atmospheric pressure, in carbon dioxide; (iv) Results are demonstrated providing information on approximate values of the current density and electric field intensity, in the region of the positive pole of the arc, for the investigated discharges in carbon dioxide. The results achieved are well formulated and presented and discussed in detail. They include consideration of conversion and energy efficiency aspects, qualitative determination of plasma discharge behavior in different configurations - non-stabilized discharge NSGD, magnetically accelerated discharge MAGD and magnetically stabilized MSGD.

The main results of the simulations of the developed two-dimensional fluid model could also be used for the deeper understanding of the processes at lower currents $\sim 10{-}1$ A. The obtained experimental results demonstrate a potential for applying the investigated technologies on an industrial scale, as well as with significant ecological effect. The scientific contributions in the present thesis work are obtained and achieved as a result of extensive research on low-current DC discharges with magnetic stabilization and magnetic acceleration, which generally shows the potential of applicability, both from a fundamental point of view and in the context of their dissociation application of carbon dioxide.

In view of the above analysis, scientific and scientific-applied contributions based on the proposed developed methods, methodologies for enriching existing and acquiring new

knowledge can be defined and evaluated as achievements with a significant contribution, both in scientific circles and in industrial and environmental aspect.

5. Critical remarks and recommendations on the submitted works.

I have no significant critical remarks on the dissertation work and the Author's abstract in terms of analyzes and summaries, methodical level, accuracy and completeness of the results, and literary awareness. The exception is some minor technical inaccuracies that do not affect the value of the dissertation work. I have no critical remarks and recommendations to the essence of the candidate's scientific work and activity. I believe that in the future the scientific works of Vladislav Ivanov will continue to be so atractive and interesting.

6. Personal impressions of the candidate

The personal impressions are based on the meeting held during the candidate's presentation. Based on that, I can express an opinion about a scientist with a well-established scientific practice and knowledge of developments and research in the field of expertise presented.

7. Conclusion

After getting acquainted with the presented dissertation, abstract and other materials, and based on the analysis of their significance and contained in them scientific and scientific-applied contributions, I confirm that the scientific achievements meet the requirements of ZRASRB and the Regulations for its application and the relevant Regulations of Sofia University “Kliment Ohridski” for obtaining the scientific degree “Doctor of Physical Sciences”. The candidate satisfies the minimal national requirements in the professional field and no plagiarism has been established in the dissertation, abstract and scientific papers submitted at the competition.

I give my positive assessment of the Thesis.

II. OVERALL CONCLUSION

Based on the above, I **recommend** the scientific jury to award the degree of "Doctor "/PhD in the professional field 4.1 Physical Sciences **to Vladislav Valentinov Ivanov.**

15.05.2023 г. Reviewer: Assoc. Prof. Ekaterina Iordanova