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# **Habilitation Thesis**

**Applications of atmospheric pressure  
plasma sources in life sciences**

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# Summary of Habilitation Thesis

The habilitation thesis „*Applications of atmospheric pressure plasma sources in life sciences*“ presents scientific and managerial results obtained after the PhD thesis defence, with special attention devoted to results concerning the use of plasmas at atmospheric pressure in life sciences. The research field is highly interdisciplinary, thus most of the experimental scientific results were obtained after successful collaborations with national and international research groups, in the frame of bilateral research projects or studies involving undergraduate, master and PhD students. In this sense, one of the personal successes is the establishment of long-term national and international collaborations, with new research groups and the realization of joint research programs.

Plasma, as a high energy environment in which many elementary atomic or molecular processes can be controlled or tuned, represents a technological solution for many civil applications, since the very beginning of first modern scientific observations. The synergistic contribution of all active components, such as electrons, ions, photons, free radicals and fields, to various physico-chemical processes, has attracted much attention from researchers and entrepreneurs. The rapid development of some high tech industrial areas, such as microelectronics - nanoelectronics and the deposition of thin layers for various applications, is mainly due to the scientific achievements in the field of low pressure plasma processing. Many ideas using plasma as a key element have been pushed to increased technology readiness level or product level: electron or ion sources, light sources, spectral sources, high performance etching systems, thin layer deposition systems, displays, material surface modification systems, sterilization systems, electrocoagulation or cauterization devices, exhaust gases control systems, ionic or Hall effect thrusters, flight control systems.

This technological and market picture shows the lack of frequent applications in medicine, biology or other life sciences. The key limiting factor for this might be represented by the legislative requirements, which creates a significant delay between laboratory observations, technology validation in the laboratory and the actual construction of certified medical devices. Very few companies have succeeded in bringing a medical device to market, based on plasma in direct contact with living tissues. However, the scientific community is very dynamic, recent studies showing clearly that plasma is effective in destroying a broad spectrum of microorganisms, spores and biofilms, architectures that are difficult to destroy using conventional methods. Other successful medical applications involving plasmas are: enhanced wound healing, treatment of skin diseases, modification of cancer cells metabolism, teeth whitening. The efficient action of plasma sources at atmospheric pressure is linked to the synergistic action of the active agents in the plasma volume: UV photons, pulsed electric fields, electrically charged particles, free radicals and metastable species. Thus, even the simplest source of plasma processing at atmospheric pressure is a very complex system, as well as the physico-chemical reactions at the interface plasma - cells / bacteria / tissues / biomolecules / seeds.

Information concerning the focus of the scientific community on the plasma and life sciences research field, can be identified by simply analysing the topics of the international conferences devoted to plasma physics and applications. Thus, in addition to the topics devoted to surface treatments for biomaterials or the engineering of bioactive surfaces, some conferences included in the scientific program, either topics dedicated to plasma applications in life sciences, or workshops

and special meetings. The latest examples are: International Conference on Phenomena in Ionized Gases - ICPIG (topic Medical, biological, environmental and aeronautical applications for the 2019 edition), International Symposium on Plasma Chemistry - ISPC (topic Plasma medicine and plasma agriculture section for the 2019 edition) , Europhysics Conference on Atomic and Molecular Physics of Ionized Gases - ESCAMPIG (in 2018, one of the specially organized meetings was Plasmas in Medicine), International Conference on Plasma Surface Engineering - PSE (topic Biomedical and biological applications for the 2018 edition). In Romania, the scientific community received the international signal rapidly and integrated in the International Conference on Plasma Physics and Applications (CPPA) a topic dedicated to the field since 2007, entitled Plasma applications in environment management, biology, medicine and agriculture for the 2019 edition. New scientific events dedicated to plasma applications in life sciences have been proposed and strengthened during the last decade, especially to provide a new forum for discussions on plasma physics and emerging applications in engineering, chemistry, biochemistry, food industry, agriculture, biology, cosmetics, pharmacy or medicine: International Conference on Plasma Medicine - ICPM, International Workshop on Plasma for Cancer Treatment - IWPCT, International Workshop on Plasma Agriculture - IWOPA, International Meeting on Plasma Cosmetic Science - IMPCS. A number of new scientific journals are exclusively or partially devoted to scientific studies in the field: Plasma Medicine (Begell House Publishing), Clinical Plasma Medicine (Elsevier B.V.) and IEEE Transactions on Radiation and Plasma Medical Sciences (IEEE). The studies published in these journals just add to the hundreds of other studies published in special issues of plasma physics journals, books, review articles, roadmap, consensus paper, white paper. Another key factor concerning the rapid development of the field is the technological transfer and the presence on the medical market or related fields (bioengineering, agriculture) with certified medical devices or technical solutions, that use plasma at atmospheric pressure and that exclude cutting, ablation systems, coagulation or cauterization of tissues, which is already well known and clinically documented. We can identify the presence of some companies, most of them recently established, which have certified on the European market medical devices or propose various laboratory solutions.

This is enough to conclude that the plasma and life sciences research field, presents a highly interdisciplinary research agenda, being continuously under development for both, national and international levels, with solid foundations for both, fundamental research activities and technological transfer or industrial research activities. Thus, attracting funds to support research in the field and concentrating human resources on this topic, will continue to growth the amount of scientific results of interest to the both, international scientific community and the community focused on technological development and transfer to medical device market, food industry or modern technologies in agriculture.

The habilitation thesis is divided into two main sections: the first is dedicated to scientific activity, after the PhD thesis defence, and the second one lists the professional and academic achievements.

The first part of the habilitation thesis begins with a description of the plasma and life sciences research field, containing information about the chronology, evolution, current global context and public funding in Romania. The work continues with the presentation of personal work to the design, implementation and diagnosis of the helium plasma jet at atmospheric pressure for direct contact on living tissues. After a review of the results at international level in

this field, which underline the presence of a scientific ecosystem distributed all over the world and extremely competitive, the experimental methods used in our laboratory are discussed, and scientific results are discussed concerning the discharge current, the plasma jet morphology, the plasma emission spectrum, the ultra-fast photography of the plasma jet, and the mass spectrometry for plasma neutrals and ions. The next section is devoted to the correlation of experimental results with the numerical modelling results for the helium plasma jet at atmospheric pressure, including here the description of the numerical model used, the experimental results and comparisons with the numerical data, along with a discussion on the role of Penning ionization processes. The fourth section of the first part of the habilitation thesis is dedicated to the personal findings on the applications of plasma in life sciences, starting with the experiments dedicated to wound healing, those dedicated to understanding the effects of plasma on protein structure and finalizing with extensive investigations to understand the plasma effects on cells. Section five includes the recent results regarding the development of novel air barrier discharge setups for direct operation in cell culture plates, for the exposure of plant seeds and for organic contaminants removal from solid surfaces. The last section includes the information relevant to the international presence: citations of scientific papers (including here also citations in high-impact work, such as reviews or books), conferences and workshops attendance with invited papers and oral presentations, reviewer activity, presence in editorial boards, member of professional societies.

The second part of the habilitation thesis begin with the presentation of the didactic and mentoring activity, here being included the academic profile, details about the supervision of students for final thesis for bachelor studies or master studies, the supervision of the research projects for the international students, hosted in our laboratory in the frame of Erasmus program, member of the commission of guidance for PhD students. Then are presented a series of coordinates regarding the management of didactic activities and details regarding the research projects at national and international level, granted by competition as project director (PD type, bilateral, CDI), involvement in the proposals submitted for the PED 2019 competition, but also coordinates of the projects not selected for funding, nevertheless they were marked with very good scores in the the evaluation process (TE, PCCDI). The section dedicated to scientific research projects ends with information on the international collaborations (e.g. COST programmes), involvement in Innovative Training Networks (ITN) proposals and mentoring (e.g. secondment in Marie Skłodowska-Curie, Individual Fellowships (IF actions)). The third section is dedicated to the management of human resources and the development of the laboratory, followed by sections that point out the awards granted for the scientific research activity (i.e. 2009, special mention at the Awards in Education, Research Category, Researcher Section of the year; 2016, Iuventus Scientiae Award of "Alexandru Ioan Cuza" University of Iași; 2017, "Dragomir Hurmuzescu" award, Romanian Academy, scientific section Physical Sciences), then the activity devoted to conferences or workshops organization, as well the social engagement, including the coagulation of an national academic consortium to run the European Researchers Night event, that has been implemented since 2013, within the FP7 and Horizon 2020 programs, Marie Skłodowska-Curie actions.

Finally, a series of proposals for the near future are presented, together with a list of bibliographic references, which exceeds 600 titles, of which the first 17 represent the core work published by the candidate starting in 2011, representative for the scientific content of the habilitation thesis entitled "Applications of atmospheric pressure plasma sources in life sciences".