Development of Biomedical Applications of Non-equilibrium Plasmas and Possibilities for Atmospheric Pressure Nanotechnology Applications

Z.Lj. Petrović, N. Puač, D. Marić, D. Maletić, K. Spasić, N. Škoro, J. Sivoš, S. Lazović, G. Malović

Abstract - In this paper we discuss the synergisms between different realms of plasma supported nanotechnologies. First the developments in plasma etching for micro and later nanoelectronics have fueled immense growth of knowledge and tools in describing non-equilibrium plasmas. This has led to detailed predictive codes and that knowledge has been used to develop a large number of new sources of non-equilibrium plasmas operating at atmospheric pressure, even in air. With those tools a new front of plasma medicine has opened wide with new possibilities and a number of promising techniques for sterilization, cancer treatment, oral cavity treatment, dermatology and in a range of applications where deposition of thin films for biocompatibility is necessary. This new front opens new possibilities in the realm of nanotechnologies with atmospheric pressure deposition of nano-structures allowing direct application of new techniques in medicine and in cheaper technologies for other purposes.

I. Introduction

Non-equilibrium plasma etching and related plasma processes [1] have proven to be the key to achieving manufacturing of integrated circuits, adherence to Moore's law and fueling of the global economy through explosion of all fields of economy that may benefit or even be generated with a strong dependence on processing power. The most important steps in developing of modern micro-electronic technology were achieved by empirical industry based research and science came in later to explain. Having said that, we must acknowledge a lot of successes in continuous improvements of the technology that were made, based on scientific development of diagnostics, modeling and fine tuning of key steps, such as multi frequency [2] and pulsed operation [3]. Finally science has made a significant contribution to understanding and removal of defects caused by the plasma itself or by the ever increasing demands in miniaturization. The contribution of science nevertheless boils down mainly to BETTER UNDERSTANDING of non-equilibrium (low temperature, cold...) plasmas. Most directly this understanding spills over to predictive models [1,4,5] that have been developed for complex geometries, complex chemistries and powering sequences and may represent realistically most of the low pressure industry devices.

At the same time there are constant reminders from the cost aware practitioners that operation of plasma devices is expensive, partly because of the need to have low pressure operation with vacuuming system to ensure the purity of gases. Operating pressures in industry are typically from few to 200 mTorr and purity of the gas that has to be achieved requires pumping down to very low pressures before the gas flow is started. Thus plasma devices operating at atmospheric pressure have been the holy grail of the industry, although some processes are not much cheaper and also cleanliness of substrates may require operation in pure gases maintained in sealed vacuum tight systems (albeit with somewhat smaller restrictions on pumping). Finally vacuum systems make production line manufacturing more complicated. In any case high pressure operation of plasma devices would be a welcome addition to the existing battery of plasma devices that micro-electronics industry has at its disposal.

Nano-particles worthy of scientific interest have been discovered first in atmospheric pressure thermal plasmas, but later non-equilibrium plasmas were shown to give some advantages and additional features [6,7]. While there are other processes that produce nano-particles, still one out of five significant papers in this field comes from the plasma background in one form or the other. Thus nanotechnologies are strongly connected to plasmas, especially non-equilibrium, and in all cases operation at atmospheric pressure would be beneficial.

Atmospheric pressure discharges and plasmas have been known in nature and have been generated by humans for the last 200 and more years. However, most of these plasmas are thermal which in principle means that electrons, ions and gas molecules tend to have the same temperature. When we calculate what is needed for ionization in order to maintain plasma, those are enormous temperatures. Yet maintaining plasma does not require all

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Encyclopedia of Plasma Technology - Two Volume Set J. Leon Shohet,2016-12-12 Technical plasmas have a wide range of industrial applications The Encyclopedia of Plasma Technology covers all aspects of plasma technology from the fundamentals to a range of applications across a large number of industries and disciplines Topics covered include nanotechnology solar cell technology biomedical and clinical applications electronic materials sustainability and clean technologies The book bridges materials science industrial chemistry physics and engineering making it a must have for researchers in industry and academia as well as those working on application oriented plasma technologies Also Available Online This Taylor E mail e reference taylorandfrancis com International Tel 44 0 20 7017 6062 E mail online sales tandf co uk **Fundamentals of Plasma Physics and Controlled Fusion** Arjun Goswami,2025-02-20 Fundamentals of Plasma Physics and Controlled Fusion is a comprehensive guide to plasma physics and the quest for controlled fusion energy We explore the study of plasmas the fourth state of matter made up of charged particles and delve into the potential of controlled fusion to create clean energy by fusing atomic nuclei We cover the basics of plasma physics including plasma behavior and creation and dive deep into controlled fusion explaining its science and the challenges of building a practical fusion reactor The book is written clearly and accessibly making it valuable for both students and researchers It also discusses fusion energy s potential to address global energy problems Fundamentals of Plasma Physics and Controlled Fusion is an essential resource for anyone interested in this exciting field of research **Nonequilibrium Atmospheric Pressure Plasma Jets** XinPei Lu,Stephan Reuter,Mounir Laroussi,DaWei Liu,2019-04-23 Nonequilibrium atmospheric pressure plasma jets N APPJs generate plasma in open space rather than in a confined chamber and can be utilized for applications in medicine This book provides a complete introduction to this fast emerging field from the fundamental physics to experimental approaches to plasma and reactive species diagnostics It provides an overview of the development of a wide range of plasma jet devices and their fundamental mechanisms The book concludes with a discussion of the exciting application of plasmas for cancer treatment The book provides details on experimental methods including expert tips and caveats covers novel devices driven by various power sources and the impact of operating conditions on concentrations and fluxes of the reactive species discusses the latest advances including theory modeling and simulation approaches gives an introduction overview and details on state of the art diagnostics of small scale high gradient atmospheric pressure plasmas covers the use of N APPJs for cancer applications including discussion of destruction of cancer cells mechanisms of action and selectivity studies XinPei Lu is a Chair Professor in the School of Electrical and Electronic Engineering at Huazhong University of Science and Technology Stephan Reuter is currently Visiting Professor at Universit Paris Saclay In a recent Alexander von Humboldt research fellowship at Princeton University he performed ultrafast laser spectroscopy on cold plasmas Mounir Laroussi is Professor of Electrical and Computer Engineering and director of the Plasma Engineering and Medicine Institute at Old

Dominion University He is a Fellow of IEEE and recipient of an IEEE Merit Award DaWei Liu is Professor in the School of Electrical and Electronic Engineering at Huazhong University of Science and Technology **Smart Nanomaterials in Biomedical Applications** Jin-Chul Kim,Madhusudhan Alle,Azamal Husen,2022-01-19 With the start of 2020 the wrath of pandemic challenged the scientific community to develop more advanced drug delivery approaches for biomedical applications endowing conventional drugs with additional therapeutic benefits and minimum side effects Although significant advancements have been done in the field of drug delivery there is a need to focus towards strategizing novel and improved drug delivery systems that should be convenient and cost effective to the patients and simultaneously they should also provide financial benefits to pharmaceutical companies Controlled drug delivery technology offers ample opportunities and scope for improvising the therapeutic efficacy of drugs via optimizing the drug release rate and time For this endeavour smart nanomaterials have served as remarkable candidates for biomedical applications owing to their ground breaking properties and design The development of such nanomaterials requires a broad knowledge related to their physio chemical properties molecular structure mechanisms by which the nanomaterials interact with the cells and methods by which drugs are released at the site of action This knowledge must also be allied with the knowledge of signaling crosstalk mechanisms that are modulated by the nanomaterial drugs composite It can be anticipated that these emerging drug delivery technologies can facilitate the world to successfully encounter such pandemic outbursts in the future in a cost effective and time effective manner The chapters in this book deal with the advanced technologies and approaches that can benefit advanced students researchers and industry experts in developing smart and intelligent nanomaterials for future biomedical applications and development manufacturing and commercialization for controlled and targeted drug delivery *Advances in Biomaterials Science and Biomedical Applications* Rosario Pignatello,2013-03-27 This contribution book is a collection of reviews and original articles from eminent experts working in the multi and interdisciplinary arena of biomaterials ranging from their design to novel uses From their personal experience the readers can obtain a stimulating foresight on the potentialities of different synthetic and engineered biomaterials 21 chapters have been organized to illustrate different aspects of biomaterials science From advanced means for the characterization and toxicological assessment of new materials through classical applications in nanotechnology and tissue engineering toward novel specific uses of these products the volume wishes to give readers a view of the wide range of disciplines and methodologies that have been exploited to develop biomaterials with the physical and biological features needed for specific clinical and medical applications

Nonequilibrium Thermodynamics Yasar Demirel,Vincent Gerbaud,2025-02-17 This fully updated and revised fifth edition of Nonequilibrium Thermodynamics Transport and Rate Processes in Physical Chemical and Biological Systems emphasizes the unifying role of thermodynamics and their use in transport processes and chemical reactions in physical chemical and biological systems This reorganized new edition provides thermodynamical approaches for foundational understanding of

natural phenomena with multiscale chemical physical and biological systems consisting of interactive processes leading to self organized dissipative structures fluctuations and instabilities This edition also emphasizes thermodynamic approaches tools and techniques including energy analysis process intensification and artificial intelligence for undertaking sustainable engineering This book will be an excellent resource for graduate students and researchers in the fields of engineering chemistry physics energy biotechnology and biology as well as those whose work involves understanding the evolution of nonequilibrium systems information theory stochastic processes and sustainable engineering This may also be useful to professionals working in irreversibility dissipative structures process exergy analysis and thermoeconomics digitalization in manufacturing and data processing Highlights the fundamentals of equilibrium thermodynamics and phase equilibria Expands the theory of nonequilibrium thermodynamics and its use in coupled reactions and transport processes in various time and space scales of physical chemical and biological systems Discusses self organized dissipative structures quantum thermodynamics information theory and stochastic approaches in thermodynamic analysis including fluctuation theories and molecular motors Includes new content on sustainable engineering with thermodynamics tools and techniques including energy analysis process intensification and artificial intelligencePresents many fully solved examples and numerous practice problemsOffers instructor resources containing a solution manual that can be obtained from the authors *Mechanics and Materials Science of Biological Materials* Krashn Kumar Dwivedi,Piyush Uniyal,Akarsh Verma,2025-07-18 This book focuses on the important experimental techniques and modeling approaches with their technological improvements and recent research advancements in the field of biomechanics The major aim of this book is to cover all updated aspects of biomechanics and materials science of biological materials and its holistic domains including the history source formulations and applications The emphasis is given on the understanding mechanics of soft and hard tissues Also many case studies are incorporated in this book that separates it from other related texts Metallic Biomaterials for Medical Applications Liqiang Wang,Chaozong Liu,Lechun Xie,2022-01-17 **Liquid Scintillation Counting Recent Applications and Development** Chin-Tzu Peng,2012-12-02 Liquid Scintillation Counting Recent Applications and Development Volume II Sample Preparation and Applications documents the proceedings of the International Conference on Liquid Scintillation Counting Recent Applications and Development held on August 21 24 1979 at the University of California San Francisco The conference brought together 180 scientists from 15 countries who share a common interest in promoting a better understanding of liquid scintillation science and technology Liquid scintillation counting is one branch of nuclear metrology that many scientists of various disciplines use in tracing and quantification in their investigatory studies The proceedings consisting of 14 sections include 76 of the 77 invited and contributed papers presented at the conference The first volume contains 37 papers mainly dealing with the physical aspects of liquid scintillation science and technology The present volume contains papers that cover sample preparation flow counting and emulsion solgel counting It also includes studies on applications of

liquid scintillation counting such as chemiluminescence and bioluminescence environmental monitoring and biomedical and radioimmunoassays *Innovative Physical Chemistry Perspectives* Praveen Kaushik,2025-02-20 Innovative Physical Chemistry Perspectives offers a refreshing take on traditional concepts in physical chemistry presenting them through innovative approaches modern applications and interdisciplinary insights Authored by experts this comprehensive volume explores fundamental principles and cutting edge research topics inviting readers to engage with the dynamic and evolving landscape of physical chemistry Each chapter delves into specific aspects providing in depth discussions theoretical foundations and practical examples From nanochemistry and biomolecular interactions to quantum mechanics and statistical mechanics we cover a wide range of topics highlighting the interconnectedness of various subfields and their relevance to real world phenomena Through clear explanations illustrative examples and thought provoking discussions Innovative Physical Chemistry Perspectives aims to inspire curiosity critical thinking and a deeper appreciation for the complexities of matter and energy at the molecular level Whether you re a student researcher or enthusiast in the field this book serves as a valuable resource for expanding your knowledge and understanding With its emphasis on modern perspectives interdisciplinary approaches and practical applications Innovative Physical Chemistry Perspectives is set to become an essential reference for anyone seeking to explore physical chemistry from new and exciting angles *Nanotechnology for Electronics, Photonics, and Renewable Energy* Anatoli Korkin,Predrag S. Krstić,Jack C. Wells,2010-12-14 Tutorial lectures given by world renowned researchers have become one of the important traditions of the Nano and Giga Challenges NGC conference series 1 Soon after preparations had begun for the rst forum NGC2002 in Moscow Russia the organizers realized that publication of the lectures notes would be a va able legacy of the meeting and a signi cant educational resource and knowledge base for students young researchers and senior experts Our rst book was p lished by Elsevier and received the same title as the meeting itself Nano and Giga 2 Challenges in Microelectronics Our second book Nanotechnology for Electronic 3 4 Materials and Devices based on the tutorial lectures at NGC2004 in Krakow 5 Poland the third book from NGC2007 in Phoenix Arizona and the current book 6 from joint NGC2009 and CSTC2009 meeting in Hamilton Ontario have been published in Springer s Nanostructure Science and Technology series Hosted by McMaster University the meeting NGC CSTC 2009 was held as a joint event of two conference series Nano and Giga Challenges Nano Giga Forum and Canadian Semiconductor Technology Conferences CSTC bringing together the networks and expertise of both professional forums Informational electronics and photonics renewable energy solar systems fuel cells and batteries and sensor nano and bio technologies have reached a new stage in their development in terms of engineering limits to cost effective impro ment of current technological approaches The latest miniaturization of electronic devices is approaching atomic dimensions

Plasma Technology for Biomedical Applications Emilio Martines,2020-05-29 There is growing interest in the use of physical plasmas ionized gases for biomedical applications especially in the framework of so called plasma medicine which

exploits the action of low power atmospheric pressure plasmas for therapeutic purposes Such plasmas are cold plasmas in the sense that only electrons have a high temperature whereas ions and the neutral gas particles are at or near room temperature As a consequence the plasma flame can be directly applied to living matter without appreciable thermal load Reactive chemical species charged particles visible and UV radiation and electric fields are interaction channels of the plasma with pathogens cells and tissues which can trigger a variety of different responses Possible applications include disinfection wound healing cancer treatment non thermal blood coagulation just to mention some The understanding of the mechanisms of plasma action on living matter requires a strongly interdisciplinary approach with competencies ranging from plasma physics and technology to chemistry to biology and finally to medicine This book is a collection of work that explores recent advances in this field *Cold Plasma* MDPI,2021-01-20 Non equilibrium plasma or low temperature plasma LTP offers a chemically rich medium without the need for high power and elevated temperatures This unique characteristic has made LTP very useful for various industrial and biomedical applications where thermal effects are not desirable In addition the relative simplicity of the design of sources capable of generating non equilibrium plasma at atmospheric pressure makes LTP a very attractive technology that can accomplish the same or better results than much more complex and expensive approaches This book describes various low temperature plasma sources and some of their environmental and biomedical applications The plasma sources covered in this book include low temperature plasma jets which are novel devices that can launch low power low temperature plasma plumes in ambient air These plasma plumes can accurately and reliably be aimed at a surface to be treated or at a biological target such as cells and tissues The application of these plasma jets in medicine including in cancer therapy are thoroughly discussed in this book The contents of this book will appeal to engineers medical experts academics and students who work with plasma technology **Government-wide Index to Federal Research & Development Reports** ,1967 *Plasma Medical Science* Shinya Toyokuni,Yuzuru Ikehara,Fumitaka Kikkawa,Masaru Hori,2018-07-06 Plasma Medical Science describes the progress that has been made in the field over the past five years illustrating what readers must know to be successful As non thermal atmospheric pressure plasma has been applied for a wide variety of medical fields including wound healing blood coagulation and cancer therapy this book is a timely resource on the topics discussed Provides a dedicated reference for this emerging topic Discusses the state of the art developments in plasma technology Introduces topics of plasma biophysics and biochemistry that are required to understand the application of the technology for plasma medicine Brings together diverse experience in this field in one reference text Provides a roadmap for future developments in the area **Plasma Assisted Decontamination of Biological and Chemical Agents** Selçuk Güçeri,Alexander Fridman,2011-10-12 Plasma decontamination is a rapidly expanding area of modern science and engineering An increasing number of engineers are using plasma methods for decontamination of chemical and biological agents Plasma decontamination is effectively applied today to clean and sterilize different surfaces high volume air and water

streams industrial exhausts and even living tissue of animals and humans This book provides a fundamental introduction to virtually all aspects of modern plasma decontamination as well as the most recent technological achievements in the area The book is segmented into four specific sections of modern plasma decontamination 1 plasma bio decontamination including disinfection and sterilization of surfaces water and air streams 2 plasma decontamination of chemical agents including cleaning of air water and industrial exhaust gases from different pollutants and especially volatile organic compounds VOC 3 plasma treatment of living tissue including different subjects of plasma medicine from skin sterilization to tissue engineering 4 major electric discharges applied for the plasma assisted decontamination of chemical and biological agents **Plasma Technology in the Preservation and Cleaning of Cultural Heritage Objects** Radko Tiňo,Katarína Vizárová,František Krčma,Milena Reháková,Viera Jančovičová,Zdenka Kozáková,2021-03-30 Scientists have long been looking for alternative methods for the cleaning of historical and cultural museum objects as conventional methods often fail to completely remove surface films leaving contamination and surface residues behind Low temperature plasmas have recently been found to provide a new efficient and durable approach that maintains the safety of both the materials and personnel This book is the first to introduce the emerging use of low temperature plasmas in the cleaning and decontamination of cultural heritage items It provides a comprehensive exploration of the new possibilities of cleaning objects with plasma before providing a practice guide to the individual cleaning methods and an overview of the technologies and conditions used in the different cleaning regimes It is an ideal reference for researchers in plasma physics in addition to professionals working in the field of historical and cultural conservation Features Provides a thorough overview of the cleaning potential of emerging plasma technologies in accessible language for professional restorers and conservators without a scientific background Includes the latest case studies from the field which have not been published elsewhere yet Authored by a team of experts in the field About the Authors Dr Radko Ti o is an Associate Professor at the Slovak University of Technology in Bratislava Slovakia Dr Katar na Viz rov is an Associate Professor at the Slovak University of Technology in Bratislava Slovakia Dr Franti ek Kr ma is an Associate Professor at Brno University of Technology Czech Republic Dr Milena Reh kov is an Associate Professor at the Slovak University of Technology in Bratislava Slovakia Dr Viera Jan ovi ov is an Associate Professor at the Slovak University of Technology in Bratislava Slovakia Dr Zdenka Koz kov is an Associate Professor at Brno University of Technology Czech Republic **NanoCellBiology** Bhanu P. Jena,Douglas J. Taatjes,2014-04-23 This book provides a comprehensive understanding of the discovery of a new cellular structure the porosome which is the universal secretory machinery in cells the protein assembly biomineralization and biomolecular interactions the molecular evolution of protein structure the use of magnetic nanoparticles for transformative application in medicine and therapy and the new and novel imaging approach of electrical impedance spectroscopy in biology It be used for college courses in nanomedicine nano cell biology advanced nanotechnology and biotechnology at the undergraduate and graduate level **Cumulated Index Medicus** ,1992

Plasma Medicine Alexander Fridman,Gary Friedman,2013-02-11 This comprehensive text is suitable for researchers and graduate students of a hot new topic in medical physics Written by the world s leading experts this book aims to present recent developments in plasma medicine both technological and scientific reviewed in a fashion accessible to the highly interdisciplinary audience consisting of doctors physicists biologists chemists and other scientists university students and professors engineers and medical practitioners The book focuses on major topics and covers the physics required to develop novel plasma discharges relevant for medical applications the medicine to apply the technology not only in vitro but also in vivo testing and the biology to understand complicated bio chemical processes involved in plasma interaction with living tissues

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