Alexander Fridman

PLASMA CHEMISTRY

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PLASMA CHEMISTRY

This unique book provides a fundamental introduction to all aspects of modern plasma chemistry. The book describes mechanisms and kinetics of chemical processes in plasma, plasma statistics, thermodynamics, fluid mechanics, and electrodynamics, as well as all major electric discharges applied in plasma chemistry. The book considers most of the major applications of plasma chemistry, from electronics to thermal coatings, from treatment of polymers to fuel conversion and hydrogen production, and from plasma metallurgy to plasma medicine. The book can be helpful to engineers, scientists, and students interested in plasma physics, plasma chemistry, plasma engineering, and combustion, as well as in chemical physics, lasers, energy systems, and environmental control. The book contains an extensive database on plasma kinetics and thermodynamics, as well as many convenient numerical formulas for practical calculations related to specific plasma–chemical processes and applications. The book contains a large number of problems and concept questions that are helpful in university courses related to plasma, lasers, combustion, chemical kinetics, statistics and thermodynamics, and high-temperature and high-energy fluid mechanics.

Alexander Fridman is Nyheim Chair Professor of Drexel University and Director of Drexel Plasma Institute. His research focuses on plasma approaches to material treatment, fuel conversion, hydrogen production, biology, medicine, and environmental control. Professor Fridman has more than 35 years of plasma research experience in national laboratories and universities in Russia, France, and the United States. He has published 6 books and 450 papers, chaired several international plasma conferences, and received numerous awards, including the Stanley Kaplan Distinguished Professorship in Chemical Kinetics and Energy Systems, the George Soros Distinguished Professorship in Physics, and the State Prize of the USSR for discovery of selective stimulation of chemical processes in non-thermal plasma.

To my wife Irene

Foreword

Although the public understanding of plasmas may be limited to plasma TVs, low-temperature plasma processes are beginning to enter into a higher level of consciousness due to the importance of plasma in many aspects of technological developments. The use of plasma for industrial purposes began more than 100 years ago with plasma sources used to produce light. Since then, plasma processes have emerged in transforming wide-ranging technologies, including microelectronics, gas lasers, polymers and novel materials, protective coatings, and water purification, and finally found their ubiquitous place in our homes. Plasma systems or plasma-treated materials are now commonly used and can be found in air-cleaning systems; food containers; fruit, meat, and vegetable treatment; fabrics; and medical devices.

In recent years, new application areas of plasma chemistry and plasma processing have been established, such as plasma nanotechnology with the continuous growth of the "dusty plasmas" domain, plasma production and modification of nanotubes, plasma aerodynamics, and plasma ignition and stabilization of flames. With the recent emphasis on alternative energy and environmental concerns, plasma chemistry has revolutionized hydrogen production, biomass conversion, and fuel-cell technology. In the same manner, the use of non-thermal plasmas in biology and medicine will likely "explode" in the coming years for various applications. Plasma is expected to soon be widely used in surgery, decontamination and sterilization of surfaces and devices, and air and water streams, as well as in tissue engineering and direct treatment of skin diseases.

In many of these applications, comprehension of detailed mechanisms, knowledge of the reaction kinetics, and understanding of the production of radicals or excited species are vital for optimization of plasma reactors and plasma processes. A growing number of universities recognize the importance of plasma technology and are preparing future professionals who are cognizant of the latest achievements in practice. Drexel University (more specifically, Drexel Plasma Institute), where the author of the book serves as the Nyheim Chair Professor, is one of the world's leading centers focused on plasma chemistry and engineering. Drexel University today makes a significant contribution to the successful development of both plasma research and plasma education and works closely with the International Plasma Chemistry Society to coordinate international activities in research, education, and outreach.

As a result of the increased interest in low-pressure plasma science, researchers and engineers are faced with the problem of evaluating the broad and varied literature from a common basis of fundamental plasma chemistry. The book that you hold in your hands meets this challenge! This book represents the first comprehensive contribution that presents the fundamentals of plasma chemistry and the scientific basis of most modern applications of plasma technologies. This book is written by my distinguished colleague and friend, Alexander Fridman, who has made outstanding contributions in the development of modern plasma science and engineering, especially in plasma kinetics of excited and charged particles, in the development of novel non-thermal atmospheric-pressure discharges, in fuel conversion and hydrogen production, in plasma sterilization and disinfection, and, more recently, in breakthrough developments in plasma medicine. *Plasma Chemistry* is of unique value to scientists, engineers, and students in the domains of plasma physics, chemistry, and engineering. It is my great pleasure to recommend this excellent work to practitioners, students, and scientists who are interested in the fundamentals and applications of plasma chemistry.

Jean-Michel Pouvesle,
President of the International Plasma Chemistry Society
Director of GREMI, University of Orleans, France
June, 2007

Preface

Plasma chemistry is an area of research that has consumed and inspired more than 35 years of the author's professional activities. During this period, plasma chemistry has become a rapidly growing area of scientific endeavor that holds great promise for practical applications for industrial and medical fields. Plasma has become a ubiquitous element that pervades many aspects of our lives. For example, the public is well aware of plasma TV, fluorescent lamps, and plasma thrusters, as well as popular-culture concepts such as plasma guns and plasma shields from *Star Trek*. Not many are aware, however, that computers, cell phones, and other modern electronic devices are manufactured using plasma-enabled chemical processing equipment; that most of the synthetic fibers used in clothing, photomaterials, and advanced packaging materials are plasma treated; that a significant amount of potable water in the world is purified using ozone-plasma technology; and that many different tools and special surfaces are plasma coated to protect and provide them with new extraordinary properties. The developments in plasma chemistry are enabling tremendous growth in a variety of applications for manufacturing, environmental remediation, and therapeutic and preventive medicine.

The motivation for this book is to provide engineers and scientists with a foundational understanding of the physical and chemical phenomena associated with both thermal and non-thermal discharge plasmas. Students pursuing degrees in electrical, chemical, mechanical, environmental, and materials engineering will find that the applications in plasma and plasma chemistry will have many important bearings in their own disciplinary areas. Therefore, the objectives and challenges of this book are to present the broad extent of basic and applied knowledge on modern plasma chemistry in a comprehensive manner for students, as well as for senior scientists and engineers.

This book also includes detailed problems and inquiries to enhance the conceptual understanding of the diverse plasma chemistry–related topics ranging from nonequilibrium processes to quantum chemistry in a manner that is readily amenable to interactive learning for students and practitioners of the topic. The problems and concept questions have been developed based on the sequence of plasma courses taught by the author at Drexel University. The book also contains extensive data tables and numerical and empirical formulas to help engineers, scientists, and practitioners in calculations of plasma-chemical systems and plasma-chemical processes. The book consists of 12 chapters; the first 4 chapters focus on the fundamental aspects of plasma chemistry, including elementary processes, physical and chemical kinetics of charged and excited plasma particles, and basic physics of gas discharges. The following 8 chapters deal with specific applications of plasma chemistry on practical implementation in areas such as electronics manufacturing, energy systems, fuel conversion, surface treatment, remediation of contaminated air and water, treatment of diseases, and destruction of pathogens.

The author gratefully acknowledges the support of his family; and support of plasma research by John and Chris Nyheim and the Stanley Kaplan family; support of the Drexel Plasma Institute (DPI) through leaders of Drexel University: Provost Steve Director, Vice Provost Ken Blank, and Dean Selcuk Guceri. The author is grateful to Professor Mun Choi, Dean of the University of Connecticut, for useful recommendations and help in working on the text. The author greatly appreciates the research support provided to DPI by the National Science Foundation, U.S. Department of Energy, U.S. Department of Defense (specifically DARPA, TARDEC Army Research Lab, and Air Force OSR), NASA, and USDA, as well as the support of our long-term industrial sponsors, Chevron, Kodak, Air Products, Georgia Pacific, Applied Materials, and Ceramatec.

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